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# 2002 Research Engineering Annual Report

*Compiled by*
*J. Larry Crawford and Everlyn Cruciani*
*NASA Dryden Flight Research Center*
*Edwards, California*

**September 2004**

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# 2002 Research Engineering Annual Report

Table of Contents

# *Preface*

The NASA Dryden Flight Research Center's Research Engineering Directorate is a diverse and broad-based organization composed of the many disciplinary engineering skills required to successfully conduct flight research. The Directorate is comprised of six Branches representing the principal disciplines of: Aerodynamics, Controls and Dynamics, Flight Systems, Flight Instrumentation, Propulsion and Performance, and Aerostructures. The Directorate organization is illustrated on the chart following this page.

The Directorate succeeded in many significant endeavors in 2002. Milestones were achieved in support of the Center's major research projects as well as in smaller, discipline focused projects, supported by the competitively funded Flight Test Techniques and Disciplinary Flight Research programs. This Annual Report encompasses the full range of those research accomplishments. It includes one-page summaries of each activity, with contact information for each of the principal investigators. A list of the many technical publications completed in the last year, from in-house, university, and contract researchers under the auspices of the Directorate is also included.

We are very proud of the accomplishments of the Directorate staff in 2002. Calendar year 2003 promises to be an even more productive year, with a mix of new and continuing research programs. I look forward to reporting on these efforts next year.

Patrick C. Stoliker
Acting Director of Research Engineering
Dryden Flight Research Center

# Research Engineering Directorate
# (Code R)

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Admin. Officer – Everlyn Cruciani
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Branch Chief – Steve Thornton
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Griff Corpening
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ALTAIR Chief Engineer
Kevin Walsh

AAW Chief Engineer
David Voracek

B-52 B/H & Pylons
Larry Reardon

J. Larry Crawford, Director
Research Engineering Directorate

9-19-02

## 2002 Research Engineering Directorate Staff

| | |
|---|---|
| Director | J. Larry Crawford |
| Deputy Director | Vicki Regenie |
| Acting Associate Director | Brad Flick |
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<u>Branch Codes and Chiefs</u>

| | |
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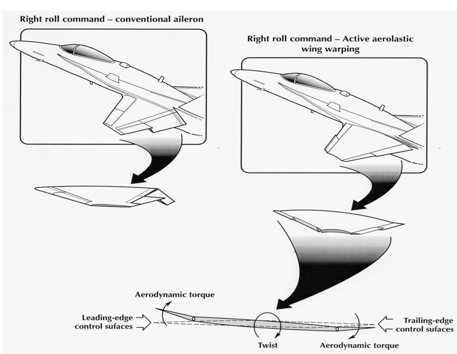
| RA – Aerodynamics | Al Bowers |
| RC – Controls and Dynamics | Joe Pahle |
| RF – Flight Systems | Bob Antoniewicz |
| RI – Flight Instrumentation | Ronald Young |
| RP – Propulsion and Performance | Dave Lux |
| RS – Aerostructures | Steve Thornton |

# Active Aeroelastic Wing Flight Research Program

Background/Objectives:
AAW Technology is multidisciplinary in that it integrates air vehicle aerodynamics, active controls, and structural aeroelastic behavior to maximize air vehicle performance. The concept uses wing aeroelastic flexibility for a net benefit and enables the use of high aspect ratio, thin, swept wings that are aeroelastically deformed into shapes for optimum performance. This makes it possible to achieve the multi-point aerodynamic performance required of future fighter, bomber, and transport aircraft.

AAW Technology employs wing aeroelastic flexibility for a net benefit through use of multiple leading and trailing edge control surfaces activated by a digital flight control system. At higher dynamic pressures, AAW control surfaces are used as "aerodynamic tabs" which are deflected into the air stream in a manner that produces favorable wing twist instead of the reduced control generally associated with "aileron reversal" caused by trailing edge surfaces. The energy of the air stream is employed to twist the wing with very little control surface motion. The wing itself creates the control forces.




Flight Test Approach
AAW flight research testing has been planned in two general phases that ensure a safe, thorough evaluation. During Phase I, functional test flights, air data calibration, and flutter and aeroservoelastic clearance flights will be accomplished. These flights will ensure all aircraft systems and instrumentation systems were functioning properly. During Phase 1, Parameter Identification (PID) flights are to be conducted. The PID flights are being done to quantify the control surface effectiveness on aerodynamics and aircraft loads. The flight-correlated relationships will be implemented in the simulation for control law development.

Flight Status
As of December 31, 2002, the aircraft has successfully completed nine flights. The first flight put the aircraft through a series of standard F/A-18 maneuvers that checked out the aircraft basic performance. The flights performed a simulated failed outboard leading edge flap maneuver. During this maneuver, the outboard leading edge flap was failed to 3, 6 and 10 degrees up. The aircraft slowed down and the handling qualities were evaluated. During two of the nine flights, the research airdata system was calibrated and the results will be used for the parameter identification flights. The integrated test block (ITB) being flown at several test points will evaluate the handling qualities of the aircraft along with identification of the maximum loads envelope. These maneuvers consist of 30-degree bank-to-bank and 360-degree rolls. Also 4-g rolling pullouts are being performed. Parameter identification maneuvers consisted of moving each control surface through a programmed computer input. The programmed input will allow engineers to evaluate the effectiveness of each surface and develop a model that can be used in future AAW control law designs.

Flight Results
The standard F/A-18 maneuvers showed that the basic aircraft handled very well and is a very solid aircraft. The failed flap maneuver also showed that the aircraft was easily handled, but did discover a wing drop at 10 degrees angle of attack in a full flap configuration. This result put a limit on the angle of attack during failed flaps.
The subsonic envelope flutter clearance was completed and the aircraft showed no structural instabilities or adverse trends.
The ITB maneuvers that have been completed have shown no adverse handling qualities due to the AAW aircraft modifications. Some high loads have been seen on the trailing edge flap and aileron control surfaces. The loads levels are in line with previous load testing on an F/A-18. But, the loads on the AAW seem to be occurring at less benign maneuvers. These load differences as well as the flight research engineers are currently evaluating the data from the PID maneuvers that were completed.

Point of Contact
David F. Voracek
AAW Chief Engineer
NASA Dryden Flight Research Center
(661) 276-2463

# AAW Loads Model Development

Background/Objectives:
One goal of the Active Aeroelastic Wing (AAW) project is to demonstrate roll control using wing twist. This goal will be accomplished through flight tests of a new control law. Accurate loads models for the AAW aircraft are critical to the development of the AAW control laws. These control laws will maximize performance while retaining stability, handling qualities and keeping loads within limits. Currently, parameter identification flights are underway to reduce risks associated with future AAW flights and to gather data for the improvement of aerodynamics models and loads models. The objective of the loads model derivation work is to create loads models that predict wing loads to within 10% rms error.

Flight Data Reduction
Data collected from individual surface doublets, windup turns, rolling pullouts, and rolls are first conditioned before they are used to derive and validate loads models. To date, most of the time spent on loads model development has been spent on data conditioning. The data conditioning steps consist of removing dropouts, time synchronization, spike removal, filtering, mapping left-wing loads to right-wing axis, and removing data at low loads.

Results and Analysis
Models of bending and torque at the wing root and wing fold as well as models of surface hinge moments will be produced with a linear technique and a nonlinear technique. The linear technique uses an in-house multiple linear regression code. Shown below is a comparison of the flight measured aileron hinge moment with the linear model prediction and the analytical pre-flight prediction for a rolling pullout.

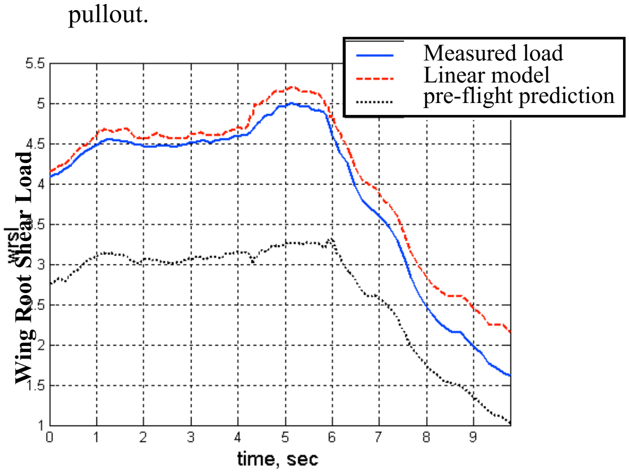


Figure 1. Shear load during a rolling pullout

The maneuver shown was used to validate the linear model and was not used to make the model.

Neural Net Results
The nonlinear technique uses a neural net to improve model accuracy when nonlinear trends are present. These trends can be due to friction, Mach effects, nonlinear control surface effectiveness, buffet, and more. To date, these effects seem to be minimal but may become more pronounced at higher Mach numbers.

The method of training the neural net is an improvement on past loads model research in that it uses the linear model as a starting point. This is accomplished by training the neural net with data generated with the linear model. After the neural net is initialized, it is then trained with flight data for a limited number of cycles. Training is stopped when iterations to the neural net no longer produce improvements in model prediction of independent validation data. These training methods have been shown to create neural net loads-models that consistently improve the accuracy of the linear models. Shown below is a time history where a non-linearity (probably buffet), caused an increase in error for the linear model that the neural net was able to overcome.

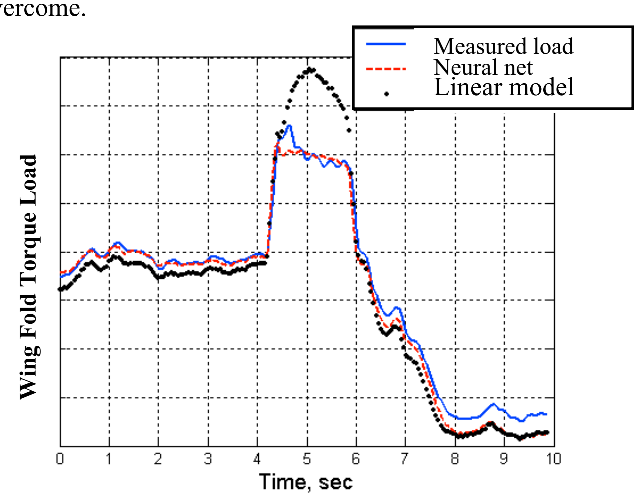


Figure 2. Torque load during a rolling pullout

Conclusion
Currently, loads models have been derived at only one flight condition, Mach 0.85 at 15,000 feet. Linear loads models are able to predict loads at this condition. The neural net method is consistently more accurate because it allows the model to become nonlinear. The accuracy of both models is sufficient for control design at this flight condition.

Point of Contact
Michael Allen
NASA Dryden Flight Research Center
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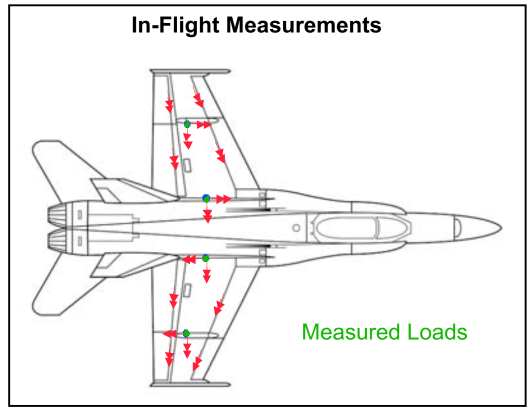
# Active Aeroelastic Wing F/A-18 Flight Loads Measurement

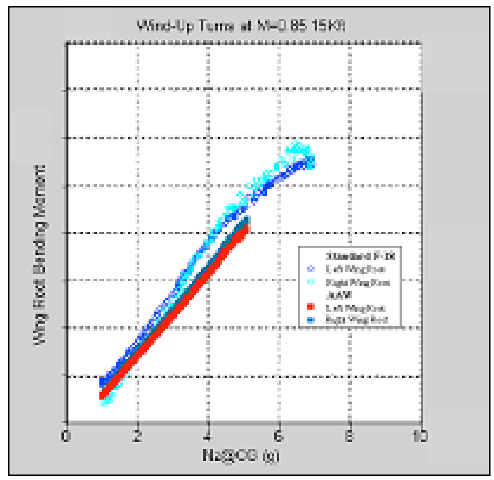
## Background and Objectives

The Active Aeroelastic Wing (AAW) project is currently in flight test gathering structural component loads data at a variety of flight conditions and control surface positions. These data will be used to develop a loads model which will then be used to contribute to the development of new control laws. These control laws will be designed to exploit wing torsional flexibility to produce roll control using the structural wing box as a primary roll effector while staying within the structural component load limits.



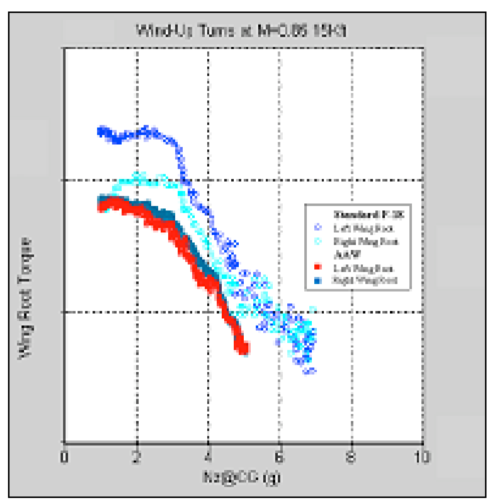

## Approach

The aircraft was instrumented with many strain gage bridges on the wing structure. Load equations for twenty wing component loads were derived from ground loads calibration test data. The appropriate strain gage signals are sampled during flight and are used to calculate flight loads in real-time. These loads are displayed in a control room during flight where they are monitored relative to structural limits. The immediate use of these data is for real-time safety-of-flight. Post-flight they are being used to develop the needed coefficients for the load prediction equations which will comprise the loads model.




## Results

The AAW flight loads have been compared to loads measured on a standard F/A-18 aircraft for the same maneuvers at the same flight conditions. As anticipated, some loads are very similar: such as the wing root bending moment, while others, such as the wing root torque, are very different. This difference is attributed to aeroelastic effects produced by the difference in wing torsional stiffness.




## Future Work

The subsonic flight test block must be completed and then the supersonic block will be flown.

**Contacts:**
William A. Lokos 661-276-3924
Rick Stauf 661-276-5667

# Active Aeroelastic Wing Flight Systems 2002

**AAW Flight Systems 2002**

The goal of the AAW Flight Research Program is to validate a new design paradigm in which a lighter, more flexible wing is used to improve overall aircraft performance. This technology demonstration uses a thin flexible wing with multiple control surfaces, including a split leading edge flap, which together produce aeroelastic characteristics that can be exploited by the application of AAW technology. Aiding the AAW project to reach that goal, the AAW Flight Systems Branch personnel accomplished many tasks in 2002 towards achieving that end.

**Aircraft Hardware Integration**

During 2002 a major milestone was accomplished in new hardware integration on the aircraft. The addition of this hardware was needed to incorporate independent actuation of the Outboard Leading edge flap (OBLEF). This included additional Power Drive Units (PDU's), as well as, Asymmetry Control Units (ACU's), which were used to provide equivalent control to the OBLEF's, as are currently present with the IBLEF's on both wings. In addition, full integration and combined system testing was done to assure correct functionality of the new hardware. The use of an independent leading edge flap combined with trailing edge control surfaces produces deflections or flexibility that can then be used in A/C roll control, which results in an optimal roll control effectiveness.

**F/A 18 Bench Platform**

Most of the Bench Hardware modifications were accomplished in 2001.

However, a large undertaking was done to provide the F/A-18 bench with a newly constructed platform to host all of the F/A-18 bench hardware that could no longer fit all the current equipment, including the new Simulation Interface Device (SID) chassis being incorporated between Flight Phases of AAW. Coordination between Safety, Facilities, Operation engineering, and Systems engineering was utilized to create the platform design and a Platform Requirements Document which were essential in creating the new platform. The Platform was assembled in early 2003.

**V&V**

As with any project, one the most important milestones is to complete the Verification and Validation testing of the flight software.

Verification and Validation of the Flight control system was conducted over several months in 2002. This culminated from a joint effort between Boeing-St Louis and NASA-Dryden, in which, Boeing took the lead during Verification Testing and Dryden took the lead on Validation testing.

Validation testing, included Checkcases, Engineering/ Piloted Failure Modes and Effects testing (FMET), Handling Qualities assessments, as well as, over 6000+ Mode Transition test cases to assure safe reliable operation of the Flight software.

**SMI**

The Flight Systems Branch supported the Structural Dynamics group in 2002 by designing and integrating a Structural Mode Interaction (SMI) DC gain box in which feedback from the Rate sensor assembly (RSA) and Accelerations Sensor assembly (ASA) were multiplied to provide the variable gain levels needed for successful testing.

**Flight Support**

In 2002 AAW began its Phase I Parameter ID (PID) Flights. Flight systems staffs both a Research Flight Control System (RFCS) station and an Aircraft Systems station in the control room.

The data from this phase of flights will be used to create a set of AAW control laws that will optimize control surface usage to exploit the aeroelastic effects resulting from the wings increased flexibility.


AAW Flight Systems Branch personnel included:

John Baca
Mike Earls
Phil Gonia
Thang Quach

Partial time:

Fred Reaux

And co-op

James Parle

# ACTIVE AEROELASTIC WING
# GROUND VIBRATION TEST RESULTS


## Summary:

Active Aeroelastic Wing will showcase a 21st century twist on an old-fashioned aircraft control technology - a high-tech derivative of wing warping pioneered by the Wright brothers almost a century ago. AAW will investigate use of lighter-weight flexible wings for improved maneuverability of high-performance aircraft through aerodynamically-induced wing twist on a full-scale aircraft.

Modifications to the F/A-18 (853) aft wing box panels and implementation of the independent outboard leading edge flap drive system on each of the Active Aeroelastic Wing (AAW) aircraft wings, altered the vehicle's structural dynamic characteristics. Ground vibration testing (GVT) and flutter analysis were required to quantify the change in frequency and wing shape of the structural modes.


## Objective:

The objective of a GVT is to measure the frequency, modal damping and mode shape of primary normal structural and verify that structural modifications to the aircraft were correctly modeled analytically. The analytical model is then used for flutter analysis. Two aircraft configurations, empty/full fuel gear up, were required for validation of the analytical model. The isolation system used to support the aircraft in a free-free boundary condition, was attached to the aircraft jack points, see Figure 1. The natural frequencies of the isolation system are 0.8 Hz in the vertical and lateral direction. The aircraft was in a flight configuration to perform the GVT, which included the control surfaces in a faired or "nulled" position using a hydraulic cart. The GVT data acquisition hardware consisted of the HP3565 data acquisition, 210 response channels, and 3 excitation sources (150lb-shakers), see Figure 2. All control surfaces but the rudders were preloaded with sand bags to eliminate the nonlinear effect of freeplay. Burst random excitation was used to get a broad-band response of the airplane and at increased force levels was used for nonlinearity checks. Symmetric and anti-symmetric sine sweeps were used to better excite closely spaced and were also performed at three force levels for nonlinearity checks.

## Results:

The lowest force level (2.6 lbs RMS) burst random excitation, identified 19 analytical modes up to 30Hz and gave the cleanest mode shape results. The GVT Mode Shapes from 6-20 Hz match the STARS (NASA-Dryden in-house code) analytical mode shapes within 10%, See Table 1. The GVT versus analytical error increases up to 30% for the Trailing Edge Flap (TEF) and Aileron rotation modes. It was noted that a large variance in GVT to analytical control surface modes is not unusual. We can attribute performing GVTs with a hydraulic cart powering the aircraft; can change the stiffness characteristics of the actuator. This area is still being investigated. To learn more about the AAW GVT Results see contact below.

## Status/Plans:

AAW is currently conducting flight test of the subsonic envelope and will continue into the supersonic envelope soon.

**Figure 1: Mounting on top of isolation system**

**Figure 2: Partial view of GVT hardware setup**

| STARS Freq (Hz) | GVT Freq (Hz) | % Error | Mode Shape Description |
|---|---|---|---|
| 5.97 | 6.241 | 4.53 | W1B-S |
| 8.85 | 8.325 | -5.93 | W1B-A, V1B-A |
| 9.00 | 8.689 | -3.46 | W1B-A, fuse rotn, slight F1B-A |
| 9.34 | 9.872 | 5.70 | F1B-S,S1B-S,some wing tip twist |
| 13.54 | 13.015 | -3.88 | S1B-A, slight wing tip twist |
| 13.61 | 13.490 | -0.88 | S1B-S |
| 14.10 | 14.534 | 3.08 | W1T-S, some S1B-S |
| 14.16 | 15.626 | 10.35 | W1T-A, V1B-A |

**Table 1. GVT Results. (Full Fuel)**


**Contact:**

Starr Potter at 661-276-3434

# Data Decompositions and Nonlinear Identification for AAW Aeroservoelastic Data Analysis


**Summary:**

F/A-18 Active Aeroelastic Wing (AAW) aircraft data is used to demonstrate signal representation effects on uncertain model development, stability estimation, and nonlinear identification.


**Objective:**

A fundamental requirement for reliable and robust model development is an attempt to account for uncertainty, noise, and nonlinearity, in particular, for model validation, robust stability prediction, and flight control system development. Data decomposition procedures are used for uncertainty reduction in model validation for stability estimation and nonlinear identification.

**Approach:**

Data is decomposed using adaptive orthonormal best-basis and wavelet-basis signal decompositions for signal denoising into linear and nonlinear identification algorithms. Nonlinear identification from a wavelet-based Volterra kernel procedure is used to extract nonlinear dynamics from aeroelastic responses, and to assist model development and uncertainty reduction for model validation and stability prediction by identifying nonlinearity from the uncertainty.

**Results:**

First and second-order kernels were extracted from AAW flight data at a flight condition of $15,000$ ft, Mach number $0.85$. The input was a multisine collective aileron sweep and the output was taken as accelerometer data from the forward right wing just inside the wing fold. Morlet filtering was applied and the filtered response with residual are shown in Figure 1.

A first-order kernel was identified from the Morlet-filtered data, which was assumed to be linear. Then, a symmetric, second-order kernel was extracted from the residual data, which was assumed to be composed of nonlinear data and noise. The identified kernels are shown in Figure 2.

The response predicted by the identified second-order kernel is depicted in Figure 3. The predicted second-order response is mostly concentrated in the $6-9$ second time range. A detailed analysis of the residual data revealed significant 12 and 14 Hz responses corresponding to input frequencies of 6 and 7 Hz, respectively. This occurred in the time range of $6-9$ seconds and is clearly indicative of a second-order nonlinearity. As shown in the zoomed-in plot in Figure 3, the second-order kernel is able to accurately predict this nonlinear response.

**Benefits:**

Accurate linear and nonlinear estimation with adaptive data decompositions as pre-processing steps to the Volterra kernel representation. General applicability to any identification scheme.

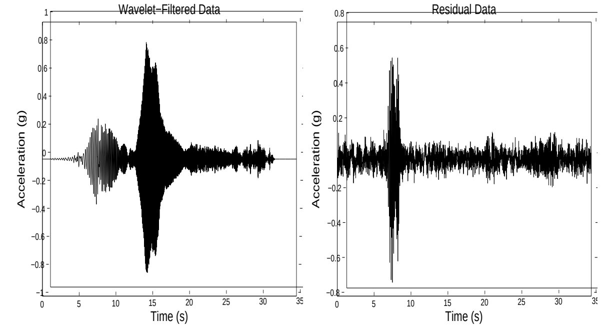



Figure 1: Morlet-filtered data and residual.

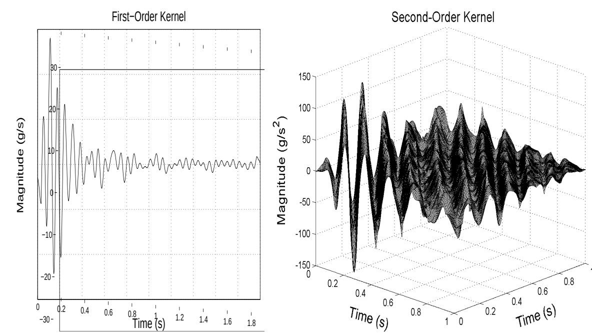



Figure 2: Identified first and second-order Volterra kernels.

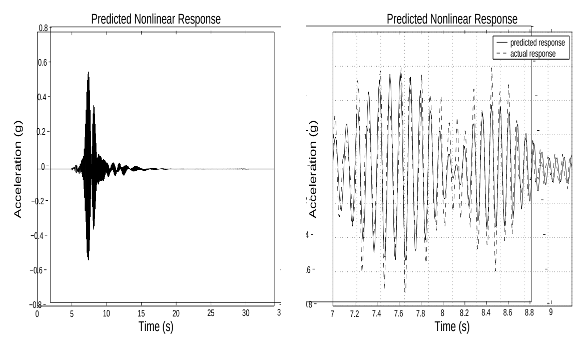



Figure 3: Nonlinear output predicted by the identified second-order kernel.


**References:**

- International Forum on Aeroelasticity and Structural Dynamics, Amsterdam, Netherlands, June 2003
- NASA/TM-2003-212021



**Contact:**

Marty Brenner, x3793, Martin.J.Brenner@nasa.gov
Chad Prazenica, x5485, Chad.Prazenica@dfrc.nasa.gov
Aerostructures Branch, Code RS
NASA Dryden Flight Research Center

# Hyper-X GNC Return-to-Flight Effort Overview

**Program Overview**

The Hyper-X research program, conducted jointly by NASA Dryden and NASA Langley, was conceived to demonstrate a scramjet engine in a flight environment. The Hyper-X Research Vehicle (HXRV), the instrument of the Hyper-X program, will be lofted to its pre-determined research test condition with the aid of a modified air-launched Pegasus booster. After separation from the launch vehicle (HXLV) and during the engine test phase, the X-43A will be commanded to follow a nearly ballistic flight path - a result of scramjet engine angle-of-attack requirements. The engine test phase (which includes post-test vehicle parameter identification maneuvers) is concluded by a recovery to a nominal descent trajectory made possible by the autonomous controller resident in the vehicle's flight control computer.

**Objective**:

The first flight of the Hyper-X vehicle was conducted in June of 2001. Problems with the Hyper-X launch vehicle occurred soon after launch. The mishap precluded the research vehicle from accomplishing any objectives. A mishap investigation was performed through Spring of 2002. The return-to-flight effort began shortly thereafter.

**Approach**:

The DFRC return to flight effort includes the development of a independent Launch Vehicle simulation (LVsim_D). Independent analysis will be performed for the control system using the LVsim_D and independent linear tools. The GNC team was also involved in an autopilot trade study where updates to the current launch vehicle control system were evaluated. Identification and review of the Pegasus anomalies is being performed to ensure that the HXLV is robust to those anomalies.


Full Scale Separation Test (FST)

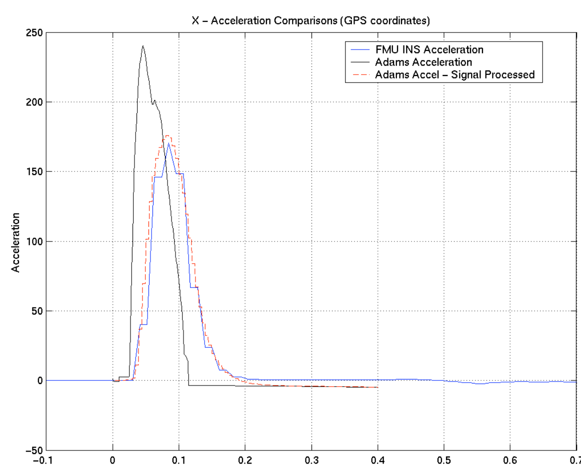
As a part of the return-to-flight effort and as further risk reduction the HXRV analysis has been reviewed. Models of the actuator, timing and sensors have been updated to increase fidelity. Many additional tests have been performed to validate the models including timing tests, actuator characterization tests, compliance testing, HIL and AIL testing. The figure below shows a picture of the Full Scale Separation Test that was conducted in the fall of 1999. The plot shows a comparison of the FMU INS acceleration seen during the test and the high fidelity sensor model prediction. The RV simulation is also undergoing a formal independent review.

**Status/Plans**:

Current work is focused on updating the independent LV simulation to a flight 2 configuration. The evaluation of the robustness of the HXLV to the Pegasus anomalies is currently being performed. The RV performance is now being evaluated in light of the updated models. The next flight is currently scheduled for the fall of 2003.


Contact:

| | | |
|---|---|---|
| Cathy Bahm | DFRC, RC | 661.276.2583 |
| Ethan Baumann | DFRC, RC | 661.276.3417 |
| Shaun McWherter | DFRC, RC | 661.276.2530 |
| Michael Richard | DFRC, RC | 661.276.3543 |
| Jack Ryan | DFRC, RC | 661.276.2558 |
| David Bose | AMA Inc. | 757.865.0944 |
| Roger Beck | AMA Inc. | 661.276.7556 |
| David Blackwell | Spiral | 661.276.7421 |


Comparison of INS Acceleration during the Full Scale Sep Test and INS Model Acceleration

# Hyper-X Launch Vehicle Propellant Offload

## Introduction

The X-43A Research Project, being conducted jointly by NASA Dryden and NASA Langley, was conceived to demonstrate the first free-flight of an airframe integrated scramjet accelerated vehicle in a flight environment. The X-43A, or Hyper-X Research Vehicle (HXRV), will be boosted to its pre-determined research test condition by a modified air-launched (from a B-52) Pegasus solid rocket booster, or the Hyper-X Launch Vehicle (HXLV). The X-43A Research Project was designed to test three research vehicles. The first two would operate at Mach 7, and the third would operate at Mach 10.

## Objective/Justification

The first X-43A Project flight failed during the HXLV boost-phase. After analyzing flight 1 data, it was determined that the probability of achieving mission success could be increased by releasing the HXLV/HXRV "stack" from the B-52 at a higher altitude, thereby significantly reducing the dynamic pressure effects. A higher altitude drop while maintaining the same HXLV/HXRV separation test conditions (altitude, Mach, attitude, dynamic pressure, etc.) requires boost performance of the HXLV be diminished. The Project investigated several ways to accomplish this including: (1.) adding ballast to the stack, (2.) modifying the nozzle, (3.) revising the trajectory, and (4.) offloading solid propellant from the motor. The Project found the best way to diminish the performance of the HXLV was by the last option, reducing the motor's total impulse. This requires a portion of solid propellant be machined from the existing motor, thereby decreasing its energy content. This HXLV propellant offload effort is specifically designed only for the second flight vehicle.

## Approach

The NASA X-43A Project investigated the option of a propellant offload through the HXLV contractor, Orbital, which is responsible for the booster system. Orbital conducted a feasibility analysis in conjunction with their subcontractor, ATK Thiokol, which is responsible for the solid rocket motor. Simultaneously, an independent Government Propellant Off-Load Team (GPOLT) was established to separately analyze the viability of offloading the HXLV. The GPOLT consisted of members from NASA Dryden, NASA Langley, NASA Marshall, NAWC China Lake, NSSC Indian Head, and US AAMC Redstone Arsenal.

## Status

When the X-43A Research Project decided to proceed with the HXLV propellant offload, machining at ATK Thiokol began by testing their manufacturing capabilities on an inert grain with the same grain geometry and structural properties as the live motor. Several "lessons learned" during the inert machining process were later applied to the live motor offload machining. While the inert machining and later live machining were being conducted, the analytical activities of all three offload teams continued.

At this time the offloaded HXLV is complete, and it has been returned to NASA Dryden where it is being prepared for the second flight of the X-43A series. Analysis/performance predictions by the GPOLT, Orbital, and ATK Thiokol are being documented.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# X-43A Actuator Compliance and Hysteresis Testing

Summary

During the first flight of the X-43A stack, the Hyper-X Launch Vehicle (HXLV) lost its right fin and rudder, resulting in the loss of the hypersonic engine experiment. In an effort to implement one of the lessons leaned from the mishap and prevent a similar fate from happening to the Hyper-X Research Vehicle (HXRV), a comprehensive set of actuation tests were performed. The highlight of this testing were the compliance and hysteresis tests. They were conducted to determine the true surface deflection under load and frictional damping. Hydraulic load jacks were used to provide the proper wing loading. Inclinometers, dial gages, and a SMX Laser Tracking System (LTS) were employed to gather the surface deflections. Compliance and hysteresis data are then incorporated into the HXRV electromechanical actuator (EMA) models as nonlinear terms and their impact on gain margins of the actuation system are analyzed.

Objectives

The objective of the X-43A compliance testing is to determine how much a control surface moves when a given load is applied to it. As the surface is loaded, force is exerted through the actuator linkages, control horn, actuator shaft, and finally into the internal gears and motor. As the load is increased or decreased, an elastic effect occurs – the actuator linkages and internal actuator components "give", resulting in movement of the control surface even though the actuator is held at a constant commanded position. For the loaded hysteresis testing, the primary goal is to determine hysteresis damping effects caused by friction and material deformation within the actuation system.

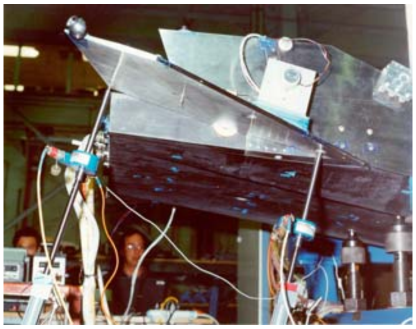
Approach

The method of approach for these two types of tests were developed by the Hyper-X flight systems and flight structures team. For wing compliance testing, two load jacks capable of delivering 80lb force each are connected to the lower part of the surface via small swivel load pads at the leading and trailing edge of the wing. The forward point is 10" away from the spindle and the aft point 12.25" away from the spindle, providing torque values up to ±1780 in-lbs. The jacks are always positioned in such a way that the applied loads are perpendicular to the surface. Load cells on the jacks allow the hydraulic system controller to make fine adjustments. For every five pound increment, surface deflection, EMA feedback, and actuator shaft travel are recorded. Surface deflections are measured using three types of sensors: an electrolytic inclinometer, a string pot consisting of a high resolution spring loaded digital dial gage, and a SMX LTS. The inclinometer and string pot measurements are taken as close to the root of the wing as possible in order to separate any effects surface elasticity and warping from the data. The LTS was employed because of its high resolution (1/4 arcsec) and accuracy. Its measurements are taken at the aft wing tip and at a body reference angle to account for the movement of the vehicle due to the loading. The linear EMA shaft travel is detected by a mechanical dial indicator mounted onto the actuator housing. The wings are tested at 0° and –15°. For the rudders, only one jack is used to impart loads up to 50 lbs (±470 in-lb at 0° and 20° outboard), and is done via a clip that is clamped onto the surface. In all cases, the actuator motors were turned off to prevent possible force fighting between the control system of the EMA and the hydraulic system used to generate the loads. A separate compliance test in which one EMA motor is energized was also conducted, however this test utilized static weights.

The hysteresis test uses the same test setup as that described for compliance. Sinusoidal loads of ±4.5, ±22.5 and ±80 lbs at 0.025Hz and 0.25Hz are applied to the wings. A data acquisition unit connected to the string pot and a pendulum inclinometer records the surface displacements. Rudder profiles are ±10.6, ±21.6 , and ±50 lbs.

Results

The compliance and hysteresis test results are currently being analyzed. Preliminary data indicates that the wing compliance are on the order of ~0.7° to 0.9°, and rudder compliance are about ~0.4° to 0.5° at the max/min torque values. Compliance will be modeled in two components: from the surface to the EMA shaft, and from the EMA shaft to the actuator-fuselage tie point. Backlash values from the hysteresis test match actuator ATP test results very well, and the hysteresis damping coefficient will be derived from the data. Once these nonlinear elements are obtained they will be added to the actuator models and incorporated into the simulation for trajectory analysis.



X43A Wing Compliance/Hysteresis Test

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# X-43C Vehicle Systems Demonstrator


Summary

The Next Generation Launch Technology office at Marshall Space Flight Center has introduced a program as part of the Hyper-X flight program activity called X-43C. NASA Langley as project office and NASA Dryden as the flight test facility, including the USAF, are developing three hypersonic flight vehicles designated as X-43C. The X-43C free flyer, called the demonstrator vehicle shall demonstrate the performance of an air breathing, scramjet engine burning hydrocarbon fuel in a hypersonic flight environment. The demonstrator vehicle (DV) is to demonstrate sustained acceleration from Mach 5 to Mach 7. The DV is to be dropped from a carrier aircraft and boosted to its predetermined test condition by a modified Pegasus rocket first stage. The DV will separate from the rocket stage and start its scramjet engine and accelerate for a predetermined time. The vehicle will then conduct specified maneuvers and drop in the ocean.

Before the DV is flown it must pass validation testing. NASA Dryden is developing a ground test platform to prepare the DV for validation testing. This platform and associated systems is called the vehicle systems demonstrator (VSD).


## Objectives

The following objectives for the VSD are planned:

- Minimize test time and test activity on the DV.
- Prepare procedures for DV validation tests.
- Conduct training for flight using the VSD and control room.
- Validate ground support equipment and ground test equipment.
- Integrate simulation models and run simulations of software.
- Perform mission simulations of the flight test to validate the DV concept.
- Validate integration of the DV.

## Approach

The VSD is to consist of the DV simulator, hardware interface unit (HIU), ground support equipment interface (GSEI), and the demonstrator vehicle emulator (DVE). The DV simulator is a flight simulator with the ability to operate in a batch as well as a real time mode. The HIU converts the simulator digital outputs to analog and discrete signal outputs. The GSEI is to be an interface panel to provide ground support equipment signals and HIU signals to the DVE. The DVE is a platform that shall be similar to the DV structure for containing DV prototype system components and wiring. The VSD systems will not be flight qualified, only acceptance tested qualified. The system components are to be incrementally provided by the contractor. A set of core components shall be provided earlier than the components for the DV to start validation testing.

## Future Work

The simulator is at this time in development along with the HIU. The other parts of the VSD are in conceptual phase waiting on contract awards for the X-43C program. Validation tests are in the planning process.

X-43C Demonstrator Vehicle

## Contacts


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# The Rocket Vehicle Integration Test Stand (RVITS)


**Summary**

NASA Dryden, in conjunction with the AFFTC and AFRL, is establishing a Rocket Vehicle Integration Test Stand (RVITS) at the site of the historic X-15 Rocket Engine Test Facility.


**Objectives**

Edwards Air Force Base (EAFB) will reestablish the capability of supporting preflight operations for Space Launch Initiative (SLI) programs and related technologies. Potential vehicles and projects requiring this facility in the near future may include X-37, RBCC, TBCC, X-43B, and PDE. This facility will be used to:

- Provide fully integrated vehicle validation.
- Trouble-shoot after propulsion system anomalies and modifications.
- Reduce technical and operational risks.
- Hot-fire installed engines in a controlled environment that is compatible with several types of propellant requirements.

**Justification**

NASA is undergoing an agency-wide push to develop new and advanced Access to Space technologies. Dryden has a key role in the flight development of these technologies. RVITS will provide a critical ground test facility at Edwards for supporting flight operations, and conduct integrated vehicle/propulsion system check-out of Access to Space vehicles.

A continuing flight program requires these ground testing capabilities, not only initially, but typically throughout the flight program. Having this capability helps to ensure mitigation of risks, which leads to an increase in flight safety and increased probability of reaching mission success.

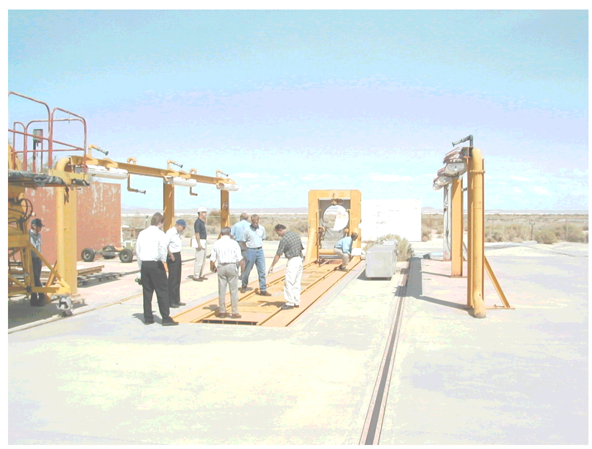
**Approach**

Although heavily utilized in the 1960's and 1970's, the X-15 Rocket Engine Test facility has been unused for several decades. Future needs for these ground testing capabilities have developed the interest of the EAFB community in rehabilitating this site to meet the requirements of future Access to Space vehicles. A feasibility analysis has shown that rehabilitation of this existing site will save hundreds of thousands over rebuilding these capabilities. The optimal location of the site is also a major advantage, being located directly off of the delta taxiway for easy access, while distant enough for safety considerations.

**Status**

Several accomplishments have been achieved since rehabilitation efforts for RVITS were initiated, but the greatest tasks have been completed just in this last year. Some of these completed tasks include the following:

- Thousands of pounds of debris and weeds were removed in a thorough cleanup effort.
- A feasibility analysis was completed, assessing the structural integrity of the existing infrastructure for future use.
- Design and detail drawings for rehabilitation were released into AFRL's configuration control system. These designs focus on general requirements of a typical rocket-powered vehicle utilizing the stand.
- The nearby LOX storage facility has been relocated further from the RVITS site.
- The first construction phase is near completion.
- The entire RVITS area has been resurfaced with asphalt to reduce trip hazards and FOD concerns.
- Concrete work at the site is near completion, ensuring the site's compatibility with LOX as well as other rocket propellants.
- Major work on the deluge sump is near completion, and construction will include a dam with valve-control for containment as necessary.



*RVITS Test Stand Before Rehabilitation*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(NASA TM currently in production)

# X-37 Approach And Landing Test Vehicle (X-37 ALTV) Program


**Summary**

From the Flight Systems perspective, the ALT project requires flight test at Dryden Flight Research Center (DFRC) of an autonomous, Approach Landing Test Vehicle (ALTV) constructed by Boeing under contract with NASA Marshall Space Flight Center (MFSC). An Orbital Vehicle (OV) also under contract with Boeing will differ from the ALTV due to design departure and is not covered by this brief, except as a matter of coincidence. The ALTV will be mounted to a NASA B-52H through a pylon. The B-52H has been modified for this project with the addition of two cameras with recording capability; Launch Panel Operator (LPO) station; a cockpit display; communication telemetry; and pylon mountings. The adaptive pylon includes wiring from the ALTV to Launch Panel Operator (LPO) station; power; and one video camera located in the pylon. The pylon is intended to serve this and future experiments. For ALTV a drogue chute has been included. The ALTV has an incorporated Flight Termination System (FTS) developed jointly by NASA and Boeing. DFRC has primary responsibility for B-52H, its crew and range safety.

MSFC and Boeing responsibilities include the ALTV, mission success, the Flight Operations Command Center (FOCC), and data analysis.


**Objectives**

The primary technical objective of the X-37 ALTV project is to provide risk mitigation for a shuttle payload unmanned vehicle, the OV. In support of this primary objective, flight test of the ALTV will yield results for the following technical objectives at a minimum for the re-entry portion of the OV's mission:

**ALTV**

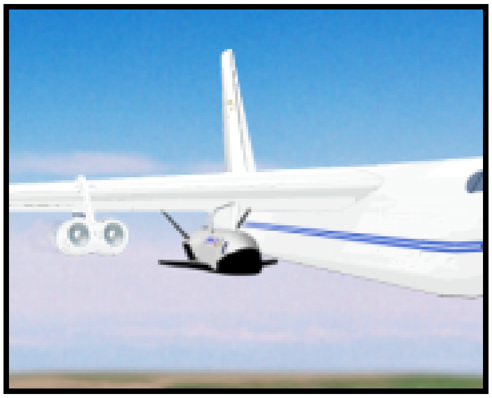
Uncover unanticipated problems through flight tests of the guidance, navigation and control, communications, radar altimeter, flight control and vehicle control systems from 40,000+ ft launch to approach and landing under actual flight conditions. Evaluate systems, materials, and components under actual flight environment conditions.

**B-52H and Range**

The B-52H is expected to replace a venerable B-52 (NASA 008), which has been used at Dryden for several decades to launch from high altitude many famous, important research vehicles. The "new" B-52H has a wet wing, defining allowable modifications, which are different from 008, such as cutting back the right inboard flap. Modifications to the B-52H have been designed to accommodate the X-37 project needs with a clear vision for future potential needs. Range assets are planned to be acquired and/or modified in a similar fashion to serve both X-37 ALTV and OV.

**Justification**

The research value of the X-37 program is valuable toward a maneuverable space plane as well as space station crew recovery system(s) of the future. The ALTV flight tests will either verify the correctness of the design approach or identify deficiencies in the configuration to allow correction. Lessons learned during this program should be applicable to both the OV and space plane (OSP) programs of the future.



**Approach**

The ALTV will be captive carried from Edwards up to 40,000 ft before returning to base to evaluate data. Pending acceptable results, the flights will then go to altitude 40,000+ ft and release the ALTV for free autonomous flight to land at Edwards. First flight is anticipated to take place in 2004. The goal is to have 1 captive carry flight and 4 air launches from 40,000 ft by fourth quarter of 2004.

**Results to Date**

- DFRC Aero and Controls identified safe separation issues to the project. Their findings were substantiated by contractor studies and resulted in the adoption of a drogue chute system in 2003.
- Involvement, even though reasonably late in the ALTV's design process, has benefited development with several minor design changes.

**Benefits**

- Reduced Risk for emerging space plane requirements.
- Lessons Learned applicable to re-entry vehicles development programs.

**Contact**


| | |
|---|---|
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NASA Dryden Flight Research Center

# X-37 Safe Separation Analysis Approach

**Introduction:** The X-37 Approach and Landing Test Vehicle (ALTV) is an experimental autonomous vehicle that began development under NASA's space launch initiative to demonstrate technologies that would reduce the cost of access to space. Being built by Boeing's Phantom Works under a NASA contract, the X-37 ALTV will be 27.5 feet long with a wingspan of 15 feet, and weigh approximately 7,000 pounds.

**Summary:** In preparation for its launch into space, approach and landing tests from the NASA B-52H will be conducted at DFRC next year. One of Dryden's primary responsibilities on this project is to ensure a safe, clean separation of the X-37 from the B-52H. For drop tests, precautions are taken to ensure that the research vehicle may not maneuver in a way to contact any portion of the carrier aircraft. Historically, these precautions include pinning the vehicles control surfaces and commanding all control surfaces to fixed positions until clear of the carrier aircraft.

The X-37 has some characteristics that make ensuring safe separation more difficult than previous vehicles. The X-37, like the space shuttle, is a space reentry vehicle with a low aspect ratio wing. It has large control surfaces (full flying ruddervators, ailerons, and body flap) in order to maintain vehicle attitude at high angles of attack during reentry. It boasts a high lift to drag ratio for this class of vehicle (L/D>4), and is relatively lightweight.

**Objective:** The DFRC challenge was to ensure safe separation of a vehicle which has the control power and performance to recontact the B-52H. It is very statically unstable which means the control surfaces may not be locked for any amount of time after separation, and the software which controls the vehicle is only tested to level B. This standard is not considered reliable enough to guarantee safe separation. Due to these factors the recontact hazard was categorized as a 1D (Severity = Catastrophic, Probability = unlikely but possible). Without mitigations, this hazard will be an accepted risk; however, with more than two years until the first flight test, the team was required to come up with mitigations for this hazard.

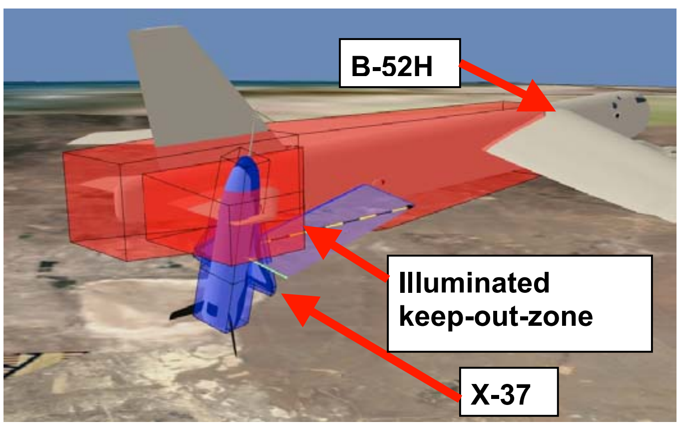


**Figure 1: X-37 Recontacting B-52H**

**Approach:** The primary analysis tool used for the separation analysis is the DFRC X-37 piloted simulation and associated graphics. A graphics model of the X-37 and B-52H were created for visualization purposes. In order to aid the analysis a "keep-out-zone" was defined around the B-52H and integrated with the graphics. If any portion of the X-37 enters the keep-out-zone during separation, the keep out zone illuminates red while the violating X-37 portion turns blue. Figure 1 illustrates the concept. Note that the fuselage and wings are blue while the ruddervators and noseboom are not.

Due to the interference effects of the B-52H, conservative aerodynamic uncertainties were applied to the aerodynamic model. Additionally, a model of the downwash and sidewash of the B-52 was added. Two types of failures were modeled to determine if recontact was possible. Open loop surface failures were modeled by failing surfaces to intermediate and maximum deflections. A generic software fault was modeled using the so-called hostile vehicle approach.

The hostile vehicle approach models a generic software fault by assuming the worst case combination of surface positions may occur. Integrating a simple three-axis piloted control system into the simulation approximated this. The sim pilot makes every attempt to recontact the B-52 by flying into it. This technique allowed DFRC engineers to quickly evaluate the severity of a recontact event and mitigations, and is paramount in this analysis.

**Results:** The preliminary simulation runs showed that without mitigations, the X-37 could cause significant damage, including loss of vehicle, to the B-52. These failures must occur within the first second after separation.

Many mitigations were evaluated in the DFRC simulation. They include, mounting the X-37 at negative angles of incidence on the pylon, limiting surface movement, rate limiting actuators, prepositioning surfaces, blowing a cold jet, sliding down four foot guide rails, carrying a 1500 lb ejectable slug, and a deploying a drogue chute. Most showed promise for mitigating the recontact hazard; however, the only one that proved agreeable to all parties was to deploy a drogue chute prior to separation. The drogue remains attached to the X-37 for 2.8 seconds and is released.

Some added benefits of the chute are it increases the pitch and directional stability of the X-37 in a highly uncertain aerodynamic environment. The chute will be mounted on the B-52 pylon, thus reducing the design impact to the X-37.

**Status:** The X-37 project is currently integrating the drogue chute into the X-37 design. Tests are being conducted to characterize the chute while attached to the X-37 and after it is released.

**Contacts:**

| | | |
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# Reusable Launch Vehicle Simulation of an Exo-Atmospheric Zoom Climb Maneuver

Summary:
DARPA has proposed the development of a two stage system to deliver a small payload to orbit. The proposal calls for an airplane first stage RLV to perform an exo-atmospheric zoom climb, where a small rocket (ELV) is launched to boost the payload into orbit. NASA DFRC engaged in an in-house generic simulation study to investigate the RLV profile, using a modified fighter-type fixed-base real-time pilot-in-the-loop simulation, complete with pilot controls and external visual imagery, as the first stage of a generic RLV.

Objective: The goal of this research was to identify real-time RLV trajectory guidance and Head-Up Display (HUD) concepts, document RLV handling qualities during the exo-atmospheric zoom climb maneuver, and characterize the ELV launch condition error, along with the corresponding errors in the transfers to the operational orbit.

Justification: ELV designers must allow for enough propellant to compensate for errors in launch condition introduced during the RLV trajectory. This study is to provide insight on potential launch condition deviations to ELV designers and insight to RLV guidance algorithm designers on which launch condition requirements are most influential on the ELV transfer orbit.

Approach: A Mach 2.5 fighter-type aircraft simulation was modified for the simulation study. Modifications included the implementation of a reaction control system, an extension of the aerodynamic model in Mach number, the implementation of a simple thrust augmentation model, and the development of a guidance algorithm which generated commands to ILS-type needles for a pilot to follow. The needles were driven by the error between the current state and a reference trajectory shown in figure 1. The ELV launch condition for the trajectory was defined at 1 qbar.

Four research pilots flew five test cases two times each: a nominal case, a wind shear case, a tailwind case, a 3% reduced net thrust case, and a case where the initial condition was offset in altitude and ground track. Desired and adequate performance were defined and Cooper-Harper ratings were obtained for three portions of the maneuver: level acceleration, zoom, and ballistic.

The ELV launch condition for each run was calculated and inserted into transfer orbit equations to determine which launch condition parameters were most sensitive to the final ELV orbit. Dispersions to the ELV reference launch condition were also calculated.

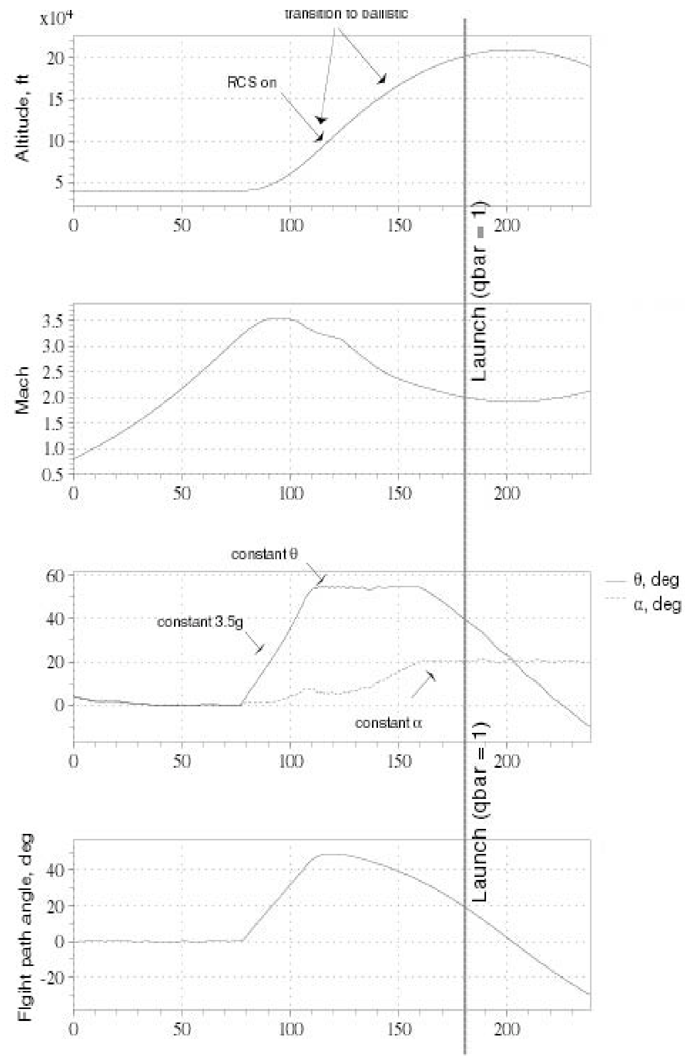


*Figure 1: Reference zoom-climb trajectory*

Results:
1) The level acceleration portion of the maneuver was rated level 1, the zoom portion was rated level 2, and the ballistic portion, where RCS was required, was rated level 1/2.

2) The ELV could not reach the desired operational orbit for the reduced net thrust case. Future guidance algorithms must be designed to compensate real-time for reduced thrust situations (e.g. 'hot' days).

3) All the other cases resulted in cumulative dispersions in the ELV launch condition of -1150' in altitude, -.05 in Mach, 1.8° in flightpath angle, -1.5° to 2.5° in azimuth, and +3s to -4s in time.

4) The ELV launch condition parameters which influenced the transfer orbit the most were flightpath angle and azimuth.

References: AIAA-2003-5544 to be published
Contact: Timothy H. Cox , Peter Urschel, Dynamics Branch, X-2126
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# NASA F-15 Intelligent Flight Control Systems – Gen I


## Summary

The goal of the F-15 Intelligent Flight Control System (IFCS) program is to demonstrate in flight that a learning system can be used to increase the survivability of an aircraft under failure conditions that change the vehicle aerodynamics - such as locked or biased control surfaces or aircraft damage. The IFCS concept could also be used to help ensure acceptable flight performance of new vehicles that may have inaccurate or limited aerodynamic data from wind tunnels. The F-15 IFCS program separates this research into two phases: Gen I (Indirect Adaptive) and Gen II (Direct Adaptive). This report summarizes the recent progress on the Gen I flight control law development.

The Gen I concept is an indirect adaptive approach. The system uses a real-time parameter identification (PID) algorithm to identify dynamic characteristics of the vehicle (stability and control derivatives). When the PID estimates differ from the derivatives computed by the pre-trained neural network (PTNN), the differences are sent to the on-line leaning neural network. The Dynamic Cell Structure (DCS) network is used to map and store the changes in stability and control derivatives over the flight envelope. The modified derivatives are then used by the flight controller to stabilize the vehicle and provide desired flying characteristics.


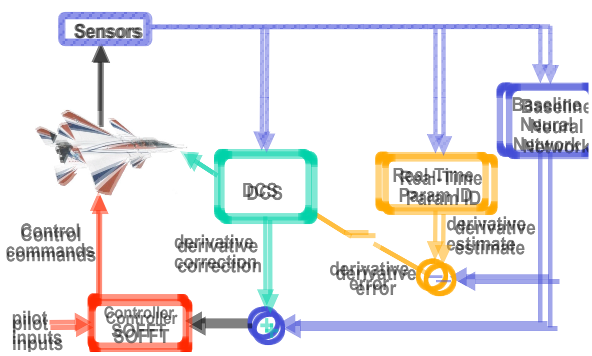


**Figure 1: Gen I Overview**

## Objective

The IFCS Gen I program objective is to utilize neural network technologies to efficiently identify aircraft stability and control characteristics and utilize this information to optimize aircraft performance in both normal and failure conditions.

## Justification

Neural Networks have demonstrated in simulation the ability to identify and adapt to unexpected aircraft dynamics. This technology will provide increased safety and more effective control law design.

## Approach

The Gen I program has three flight phases. The Build 1, Drop I (Risk Reduction) flights are intended to test the performance of the new Airborne Research Test System (ARTS II) computer. The ARTS II is a faster, more capable computer that allows for the hosting of the neural network algorithms. The DCS and PID are not on-board, but collected data will be used to help develop and refine the PID and DCS algorithms though post-flight analysis. Once the Drop 1 flights are completed, the program will move to Passive Mode flight tests (Build I, Drop 2) during which the DCS and PID algorithms will be flown open-loop in the ARTS II computer. Both the risk reduction and passive mode flight tests are preparation for the Build II flight tests. During Build II the PID and DCS will run closed loop with the flight controller. The Build II flight phase will also include simulated surface failures.

## Results

The program has completed the Build I, Drop 1 flight test phase. A total of seven flights were flown. Post-flight analysis indicates the PTNN worked as expected and handling qualities of the system have remained unchanged with the new ARTS II computer. Data collected at both subsonic and supersonic test conditions is being used for development of PID and DCS algorithms.

## Status

The program is preparing for flight tests with PID and DCS in passive mode. This system is currently being tested in the hardware-in-the-loop simulation at Boeing in St. Louis. Preparation for the Build II flight tests also continues, with a Critical Design Review planned for April and flight tests expected to begin in December 2003.


**NASA F-15 # 837**

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# NASA F-15 Intelligent Flight Control Systems – Gen II


## Summary

The Second Generation control system for the F-15 Intelligent Flight Control System (IFCS) program implements direct adaptive neural networks to demonstrate robust tolerance to faults and failures. The direct adaptive tracking controller integrates learning neural networks (NN) with an inverting control law. The term “direct adaptive” is labeled as such because the error between the reference model and the actual aircraft response is being modified or “directly adapted” to fit the reference without regard to knowing the cause of the error. Unlike the First Generation (Gen I) approach, no parameter estimation is needed for this control system.


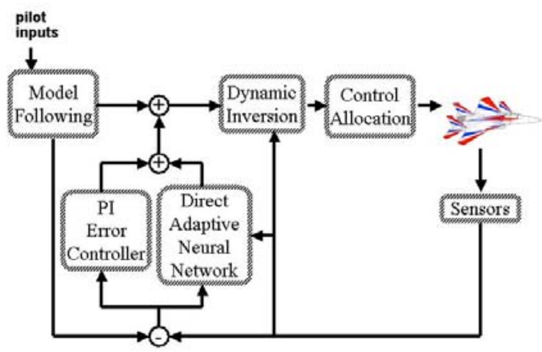


**Figure 1:** Direct-Adaptive, Neural Net Flight Control

In the Gen II design (Figure 1), the feedback errors are regulated with a proportional plus integral (PI) controller. This basic system is augmented with an adaptive neural network that operates directly on the feedback errors. The direct adaptive approach incorporates neural networks that are applied directly to the flight control system feedback errors to provide adjustments to improve aircraft performance in both normal flight and with system failures. The adaptive neural network adjusts the system for mis-predicted behavior, or changes in behavior resulting from damage.

## Objective

The Gen II in-flight performance shall be evaluated under both nominal configurations and in the presence of simulated surface failures (frozen and offset). Another objective is identifying requirements and developing a process guide for qualifying learning neural network flight control software.

## Justification

The primary benefits of Intelligent Flight Controls can be divided into two categories: Safety and Cost Reduction. NASA’s safety goals are to reduce the aircraft accident rate by a factor of five within 10 years and by a factor of 10 within 25 years. For the specific category of loss of control in-flight, U.S. aircraft industry goals are to increase flyable situations following airframe damage by 20%, or to the extent possible. Another goal is to increase the flight envelope following control surface failure by 15%, or to the extent possible. These industry goals are driven by the desire to improve multi-channel fly by wire control systems so that they can automatically compensate for off nominal conditions.

A U.S. industry case study for one flight control system development cycle suggested that $0.5M savings for each software version is possible using a neural network-based flight control system. Thus, the projected cost savings for that development cycle could approach $50M.

## Approach

Flight performance comparisons will be made between Gen II with and without the neural networks activated at the same conditions and in the presence of the same failures. Performance results will be evaluated against accepted handling qualities standards such as Cooper-Harper. All flight test conditions will be coordinated with simulation evaluations in order to validate in-flight that the system performs as expected.

Flight safety considerations will limit failure candidates to those that can be accomplished safely (determined by handling qualities and structural load considerations) without thrust control and some simulated failures may also require restriction of the flight envelope. No control surfaces will actually be failed; simulated failures will be implemented by software inserting a command to hold/bias surfaces at specified values. All simulated failure candidates will be pre-tested on a piloted simulation.

Multiple neural network algorithms may be added to the research flight control computer (ARTS II) for flight test comparisons.

## Results

Simulation studies have shown promising neural network performance with and without simulated failures. Two neural network algorithms are currently being considered, Sigma-Pi and Single Hidden Layer.

## Status

Development of the Gen II control system is underway. Simulation studies compare neural network algorithms ability to adapt to modeling errors and simulated failures. Draft releases of a process guide for flight qualification of a learning neural network control software have been distributed. The Preliminary Design Review is planned for May and flight tests are expected to begin in early 2004.


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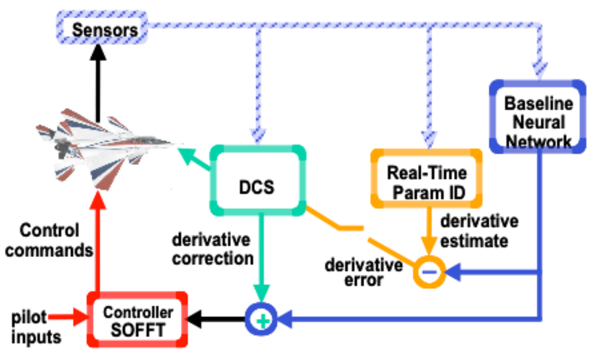
# F-15 IFCS Neural Net Flight System


**Summary**

The F15 Advanced Controls Technology for Integrated Vehicles aircraft was modified for a Neural Net (NN) experiment to demonstrate Intelligent Flight Control System (IFCS) technologies. The current phase called Gen I is an indirect adaptive approach. The delta between the Real-time Parameter Identification (PID) estimates and the pre-trained baseline neural network are input to the Dynamic Cell Structure (DCS), which is used to map and store the changes in stability and control derivatives on the flight envelope. The derivative correction is then input to the flight controller (FC) which contains a flight controller called a Stochastic Optimal Feedforward and Feedback Technique (SOFTT). The output from these control laws generates control commands as shown below.


The system described above was successfully qualified for flight test by performing various stages of standalone verification testing and progressing to closed loop, hardware in the loop simulations (HILS) including piloted evaluations.

**Objectives**

The DCS and PID software Operational Flight Program (OFP) has been re-hosted to a different onboard flight experimental computer called Airborne Research Test System (ARTS II). This is a faster, more capable computer that allows for the hosting of the neural net and PID algorithms. Verify that the system functionally is identical as the previous implementation in the Vehicle Management System Computer (VMSC). Test the software in a standalone environment using a closed loop HILS.

Install the OFP in the flight unit ARTS computer and perform functional testing on the aircraft. Develop configuration control and data downloading procedures for the ARTS II unit.

**Approach**

Perform an Integration Readiness Test (IRT), a System Integration Test (SIT), and a HILS piloted simulation where the handling qualities and failure modes are evaluated. Test the 1553 bus messages for rates, data content, and scaling. Check the failure words and non-volatile random access memory (NVRAM) data collection. Perform the testing using flight hardware as much as possible. Use piloted simulation to confirm handling qualities. Also perform failure modes evaluation to confirm fault detection, research experiment disengagement, and transients.

**Results**

The OFP was loaded on the ARTS II flight unit and functional testing was completed on the aircraft. The F15 IFCS returned to flight on 7/23/02 and completed this phase after 7 flights on 3/13/03. The ARTS II software version for the Build I, Drop I (Risk Reduction) testing was successfully completed.

The ARTS II computer performed flawlessly for the entire flight phase. These tests proved that Pre-trained neural net (PTNN) worked as expected and the handling qualities of the system have remained unchanged with the new ARTS II computer as compared to the VMSC. Configuration control procedures are in place. The log file from the ARTS II is retrieved after every flight for analysis.

**Status**

The airplane is currently undergoing modifications for the Analog Multiplexer (AMUX) parameters, which are used for real time PID estimations in support of the next phase. Also, the addition of 1553 broadcast messages has been added to the ARTS II for recording in the NASA instrumentation system. This information will be used for real time monitoring in the Mission Control Center (MCC) and for post flight analysis.

A new ARTS II OFP version is currently undergoing testing and is nearing release for the DFRC simulation and airplane integration testing. This version will have the analog PID sensor interfaces for real time PID estimates.

The next flight test phase is scheduled to begin in May 2003. These tests will validate the Passive Mode (Build I, Drop II) functions of the real time PID inputs to the DCS.

**Contact**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# C-17 REFLCS

## C-17 REFLCS Summary

The intent of the C-17 REsearch FLght Computing System (REFLCS) Build 1 is to develop a flying research test-bed for demonstration of Applied Vehicle Intelligent Systems (AVIS) technologies. One AVIS application to be demonstrated in flight is neural-net based Intelligent Flight Control System (IFCS) software. To achieve the required AVIS / IFCS research test-bed capabilities, the C-17 T-1 aircraft will be modified by integrating a set of quad redundant Research Flight Control Computers (RFCC's) in conjunction with the C-17 Electronic Flight Control System (as shown in Figure 1). Over the past year, the REFLCS Build 1 effort has progressed to the Development phase.

In order to achieve the full compliment of AVIS objectives, the capability of the C-17 REFLCS will be enhanced through incremental builds beginning with Build 2. The intent of Build 2 is to modify the RFCC software to evaluate the in-flight performance of Gen 2 CLAWS as compared to conventional CLAWS. The objective of the Gen 2 CLAWS is to demonstrate automatic compensation for degraded vehicle characteristics that may result from damage, control surface failures, or mis-predicted aerodynamics. The REFLCS Build 2 effort has recently completed a system requirements review and is currently defining subsystem level requirements and a preliminary design. Currently, REFLCS Build 2 is in the Definition phase.

Both Builds 1 and 2 will utilize a class B restricted flight test envelope. Build 3 will be a future upgrade where a class A full flight test envelope will be utilized. Currently there are plans to incorporate engine control and Integrated Vehicle Health Management (IVHM) technologies in REFLCS Build 3.

## Status & Future Work

At this present time, the C-17 REFLCS Build 1 project is considering various options to best protect the aircraft from structural damage while the RFCC's are in control of the aircraft. Efforts for a delta design review are currently in work to address this issue. Also, the RFCC H/W units are currently going through flight worthiness testing at the vendor before REFLCS system level integration and test.

For REFLCS Build 2, a System Requirements Specification was developed to support a system requirements review. Also, work has begun on lower level subsystem requirements and preliminary design in support of the Definition phase. The main thrust of the Definition phase is to define the RFCC software which consists of the following modules (as shown in Figure 2 below):

1. System Support Package (SSP)
2. Bus Data Decoder
3. Programmable Test Inputs (PTI's)
4. CLAW Shell Partition
5. Gen 2 Experimental CLAWS
6. C-17 Replicated CLAWS
7. Data Pump
8. Programmable Test Outputs (PTO's)
9. Structural Monitor
10. Bus Data Encoder

Also, a REFLCS User Interface (RUI) is being developed to select and execute various options in support of Gen 2 flight test.

Flight test of REFLCS Build 1 is currently scheduled to begin March of 2004. The REFLCS Build 2 / Gen. 2.0 flight tests are currently scheduled for December of 2005. Effort continues on build up of an in-house Hardware-In-the-Loop-Simulation (HILS). The C-17 REFLCS HILS will support development, integration and test of future REFLCS builds to support IFCS and AVIS. The HILS development is currently planned to be completed by September of 2004.

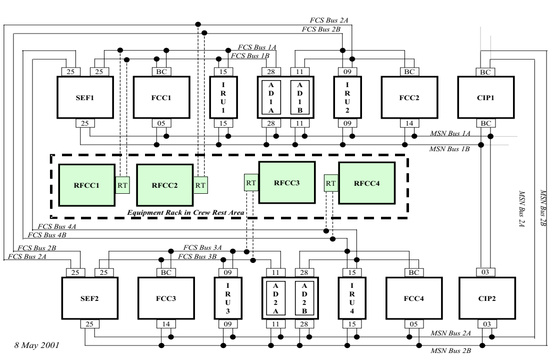


Figure 1: C-17 REFLCS Avionics Architecture

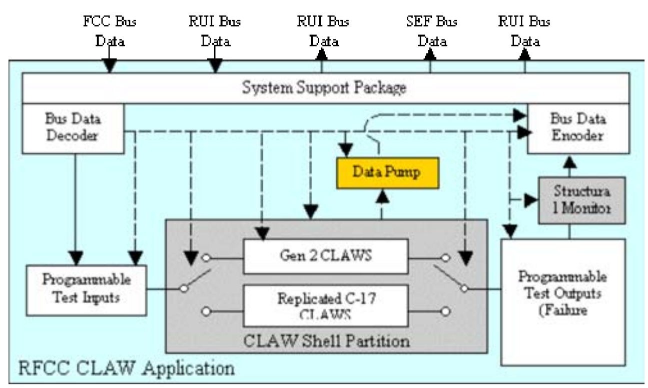


Figure 2: C-17 RFCC Software Architecture


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# Autonomous Taxi Testbed Vehicle (ATTV)


**Summary**

There is concern about the safety and logistics of integrating unmanned air vehicles (UAVs) in ground operations with manned aircraft. The goal of ATTV is to provide two flexible, low-cost, and safe testbeds for evaluating and demonstrating technologies related to UAV ground operations. This task includes developing autonomous ground control and waypoint guidance algorithms and establishing communication between two autonomous vehicles to operate both vehicles simultaneously. A build-up approach is employed to implement and test guidance, navigation, and control (GNC) software and hardware in the testbeds. This endeavor will first concentrate on a single vehicle, and then, after extensive testing, will be focused on a second testbed for tandem operation.


**Objective**

The objective is to develop two fully autonomous testbeds, operating on the Edwards lakebed, capable of working either independently or in tandem to support UAV development or other research experiments.

**Approach**

The ATTV's are Ford E150 Club Wagon vans outfitted with electronic driving controls, designed for drivers with either a limited range of motion or limited strength, to allow a convenient and safe mechanism to interface computer control commands to the vehicles.

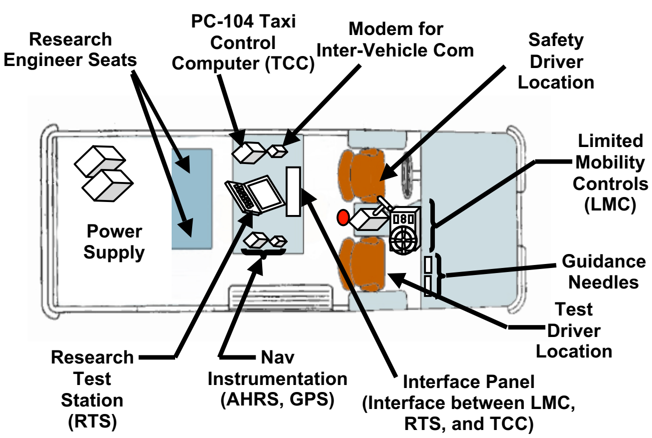


Figure 1: Autonomous Taxi Testbed Internal (Concept)

A portable Autonomous Taxi Control Computer (TCC) is located on each vehicle, performing all guidance, navigation, and control functions. An in-house designed interface panel is used for signal conditioning between the TCC and the electronic steering and gas/brake controls. A GPS receiver and inertial Attitude and Heading Reference System (AHRS) provide navigation data to the TCC. An RF communication link between modems on the two ATTVs will provide state information from one vehicle to the other. A laptop Research Test Station (RTS) provides an interface for operator commands to the vehicle during testing.

The primary test objectives are to demonstrate the ability of the ATTVs to perform GNC functions useful for comparison with UAVs in ground operations. These functions include waypoint guidance, formation taxi, and a capability for performing collision avoidance maneuvers. The 4-step build-up approach for testing is as follows:

- Single Vehicle, Open-Loop Control
- Single Vehicle, Closed-Loop Control
- Dual Vehicle, Open-Loop Control
- Dual Vehicle, Closed-Loop Control

**Status & Future Work**

A majority of the hardware has been integrated in a single vehicle and tested successfully. A final integration with the electronic steering and gas/brake controls will be completed soon, allowing system identification tests to be performed. Work is also currently being done on GNC software, which will lead to the 4-step series of evaluations.

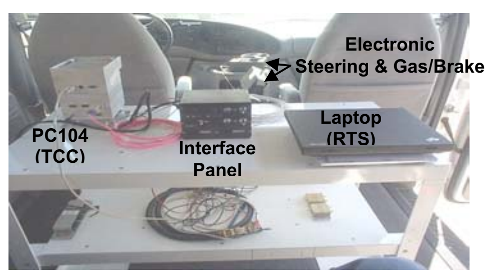


Figure 2: Partial Testbed Integration


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# Automated Aerial Refueling: Refueling Envelope Clearance

Summary
The Automated Aerial Refueling (AAR) project is evaluating the capability of an F/A-18A aircraft as an in-flight refueling tanker to develop analytical models for an automated aerial refueling system for unmanned air vehicles (UAVs). The research could also eventually aid in the development of automated refueling systems for manned aircraft.

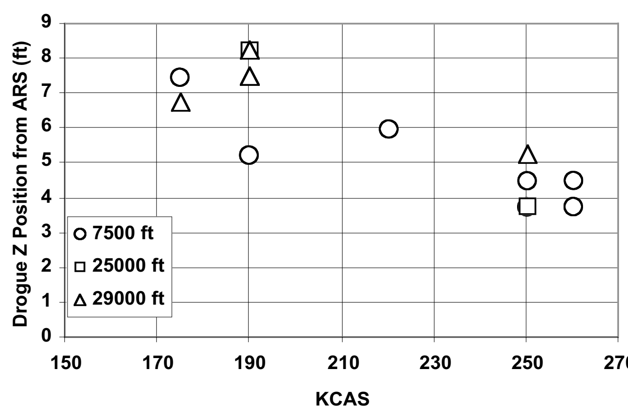
Objective
Flight data will be collected and used to generate a dynamic model of the hose and drogue trailing behind an F/A-18A tanker aircraft. The model will include the effects of free stream aerodynamics, tanker aircraft dynamics and downwash, and receiver aircraft forebody flow field. Currently little flight-obtained data exists on hose and drogue behavior. For this modeling study, a second F/A-18 is flying as the receiver aircraft. However, the results will be made extensible to various generic tanker and receiver aircraft.

Approach
The F/A-18A tanker aircraft has been outfitted with an aerial refueling store (ARS), an aerodynamic pod containing air-refueling equipment carried beneath the fuselage. This was the first time that an ARS pod was installed on an F/A-18A model aircraft. Before proceeding with data collection flights, an operational refueling envelope was cleared. The tanker aircraft's handling qualities were observed for degradations due to the ARS pod installation. Minimum and maximum airspeeds for hose extension and retraction were determined along with an envelope for refueling engagements.

Results
Envelope clearance was completed in December for tanker captive carry, hose extension and retraction and refueling engagements. These flight tests included the first ever in-flight refueling from an F/A-18A tanker. Upper limits to the aircraft's airspeed during hose retraction were identified based upon the possibility of the refueling drogue striking the bottom of the tanker aircraft. Drogue clearance was measured between test points using freeze-frame playback of downlinked chase aircraft video. The upper refueling airspeed was limited by a reduction in receiver aircraft handling qualities due to the immersion of its vertical tails in the tanker aircraft's jetwash. The lower refueling airspeed limit was defined by an inability of the ARS ram air turbine to provide enough power to simultaneously pump fuel and regulate hose tension.


NASA F/A-18 Aircraft Refueling In Flight

Preliminary measurements of the drogue's freestream vertical position relative to the tanker aircraft were obtained from analysis of video images. These results provided requirements for the camera fields of view in the next series of flight tests.




Relative Vertical Drogue Position in the Freestream

Status
The tanker and receiver F/A-18 aircraft are being outfitted with multiple video cameras on wing pylons to record motion of the drogue during flight tests scheduled for this summer. The recorded video will be used in conjunction with a video tracking system and GPS information from both aircraft to provide the position of the drogue relative to both aircraft during refueling engagements.

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Curtis Hanson, Code RC, x3966
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# Automated Aerial Refueling Performance Results: Calculated Drag of Drogue Chute


## Summary

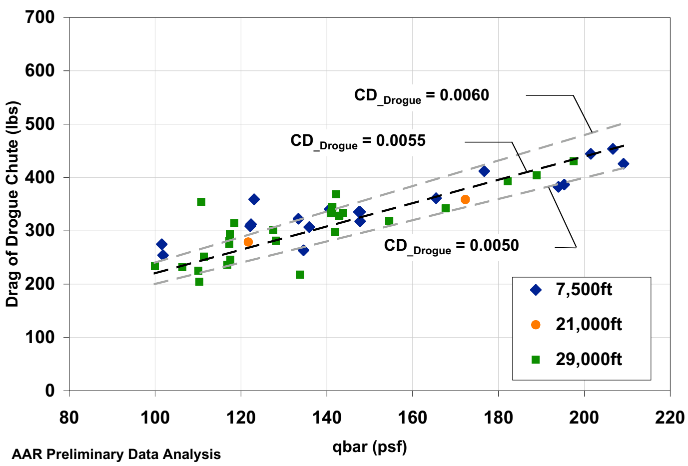
The Automated Aerial Refueling (AAR) project was conceived to map the forebody effects of a refueling aircraft on a refueling drogue chute and the feasibility of using an optical tracking system to automate the refueling task. A NASA F/A-18 was modified with an Aerial Refueling Store (ARS) mounted at the centerline station. The ARS is a ~300-gallon fuel tank with a retractable hose and drogue chute powered by a ram air turbine.

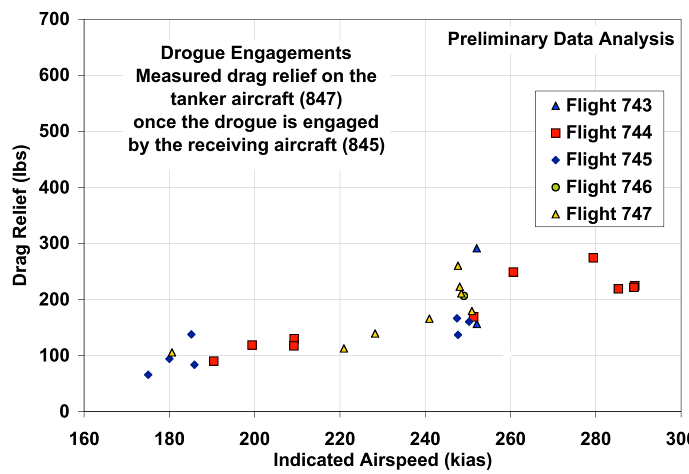
Phase 0 of the project explored the operational envelope of the ARS. Because the aircraft selected to be the tanker for this project was already highly-instrumented for in-flight thrust determination, an "add-on" experiment was developed to measure the change in vehicle drag attributable to the deployment of a refueling drogue chute.

Drag data was obtained at a variety of dynamic pressures. Drag data for the entire aircraft configuration with the drogue chute in the stowed position was compared with drag data for the deployed configuration.



*NASA F/A-18 with the ARS and drogue chute deployed*




***Summary of AAR Drag Results***

## Results

Limited, if any, in-flight drag measurements have been obtained on an aerial refueling drogue chute and hose extension system. Preliminary analysis of the AAR refueling probe system indicates the drag of the drogue chute ranges from 200 to 450 lbs for the flight conditions tested. Test conditions were flown at two primary altitudes; 7,000ft and 29,000ft for Mach numbers ranging from 0.3 to 0.66. The flight results also indicate the drag coefficient of the drogue chute appears to be about CD=0.0050 for the range of conditions tested. No aircraft trim drag corrections have been made to this data.

When the receiver aircraft engaged the drogue chute, a drag reduction on the tanker aircraft was measured and ranged from 65 to 300 lbs, depending on flight condition. This provides an indication of how much drag relief or load transfers from the refueling aircraft to the aircraft being refueled as it "pushes" on the refueling probe. Typically, up to 20 feet of refueling hose is reeled in during these engagements.

These results indicate simple performance models can be used to predict drag changes on the refueling supply aircraft and the aircraft engaging the refueling probe. Further flight testes will refine the performance database and explore the effects aerodynamic interaction has on performance of both aircraft during refueling.


Ron Ray, x3687
Jake Vachon, x3450

# APSO Skin Friction Vector Gage


Summary

Baseline (flat plate) calibration of the Adjustable-Protrusion Surface Obstacle (APSO) Skin Friction Vector Gage was conducted for speeds up to Mach 2. Results are encouraging.


Objectives

The objective of this work is to advance the state-of-the-art in pressure-based indirect measurement of shear stress and to bring to flight the capability to measure skin friction magnitude and direction on swept wings and curved surfaces.

Justification

Skin friction (or shear stress) is an essential parameter in flight research for performance evaluation and safety assessment. It is a difficult parameter to measure accurately, and there is no single preferred measurement technique. Indirect measurement techniques are popular because they are easy to use, however existing techniques are limited by factors such as pressure gradient, flow direction, and physical size. The present work is targeted at reducing the limitations caused by those factors.

Approach

The concept for the sensor is that of an adjustable, omnidirectional probe (or surface obstacle) operating at minimum protrusion levels (heights). The sensor was designed by Professor Raimo Hakkinen of Washington University in St. Louis, MO, and is shown in Figure 1. The obstacle s diameter is 10mm (0.393 ). It protrudes into the flow from the tunnel wall over a range of 0 to 2.4 mm (0.094 ). Around its circumference are 12 pressure ports spaced 30 degrees apart. Beneath the sensor is a precision actuator for adjusting the height of the probe.

Results & Status

The gage was tested at NASA Glenn Research Center (GRC) in the 8- X 6-ft Supersonic Wind Tunnel over speeds ranging from Mach 0.26 to 1.96. Results of pressure rise as a function of shear stress are plotted in non-dimensional terms (see figure 2) and show overall good consistency. Future work includes developing a compressibility correction for the higher Mach number data and developing a unifying non-dimensional relationship that covers both the GRC data and data obtained in 2000 at the Washington University Low-Speed Wind Tunnel.

Figure 3 shows how the location of maximum pressure around the circumference of the gage varies as a function of obstacle height at Mach numbers of 0.26 and 1.56. Future work includes calibrating the gage in a facility with a well-documented skewed boundary layer to relate measurements like those in figure 3 to shear stress direction.

For more information

*Exploratory Calibration of Adjustable-Protrusion Surface-Obstacle (APSO) Skin Friction Vector Gage* published as AIAA-2003-0740 and as NASA/TM-2003-210739.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Raimo Hakkinen, (314)935-4084, rjh@me.wustl.edu


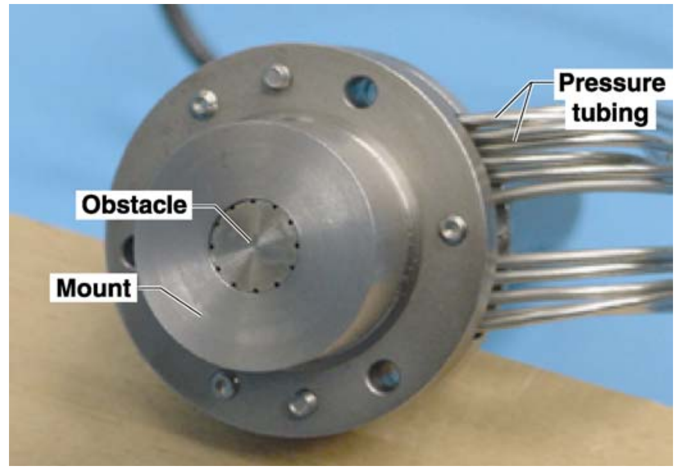


Figure 1. Photograph of the APSO Gage.

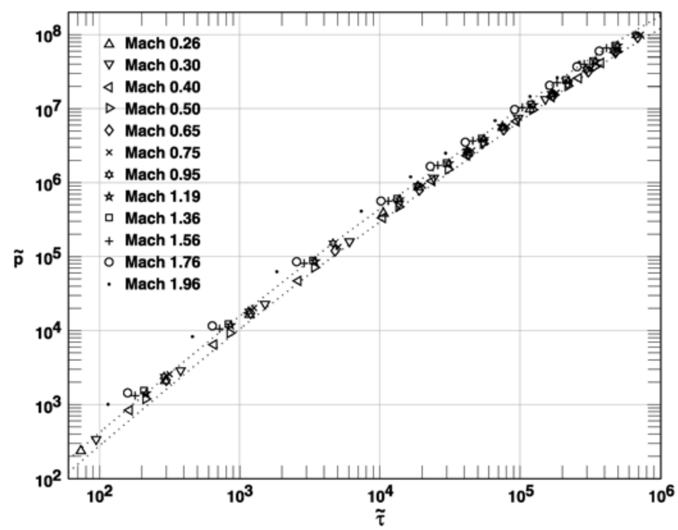


Figure 2. Maximum differential pressure plotted against shear stress (both dimensionless) for GRC test conditions.

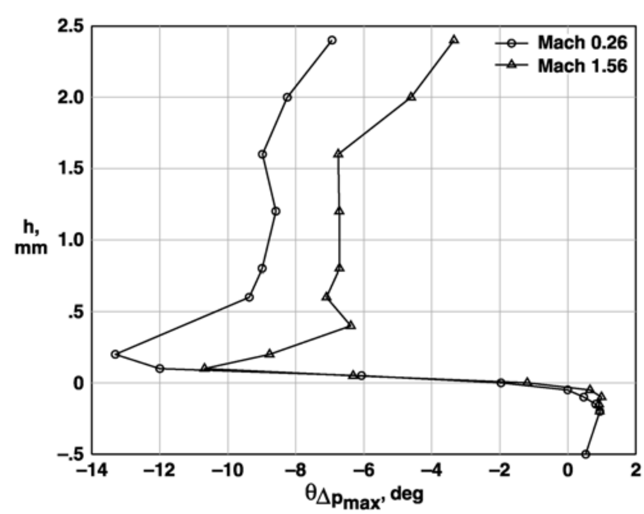


Figure 3. Protrusion height plotted against location of maximum differential pressure.

# Network Ready Smart Instrumentation

**Summary**

Flight test instrumentation based on network smart sensors has been ground tested and is ready for flight-tests onboard a Dryden radio-controlled aircraft.

**Objectives**

Develop new scalable instrumentation and data transport methods to improve flight research productivity and enhance capability.

**Justification**

Today's flight research requires greater bandwidth for telemetry and sensors with greater intelligence and inter-sensor communication capability.

**Approach**

Network sensors are integrated in an instrumentation pod (Figure 1) designed to be flight tested on a radio-controlled aircraft. Two servers provide inter-sensor communication between both airborne and ground-based sensors. Non-network sensors utilizing the RS-232 and USB interfaces are bridged into the network through a server, which handles network commands as well as serial communication with various avionics and imaging sensors. Wireless LAN radios are used to connect the airborne and the ground network. To maintain network connectivity in flight, a directional antenna is pointed to a GPS beacon mounted in the pod.

**Results**

Real-time sensor values can be displayed with a Web browser (Figure 2). Sensor descriptions, based on the IEEE-1451 standard, can also be displayed and modified. Complex subsystems such as RF amplifiers, filters, and imaging sensors can be remotely controlled. An intelligent agent monitors the dynamics of the vehicle and chooses appropriate filter settings for the GPS receiver, resulting in smooth, accurate GPS position. The agent also gathers DGPS corrections on the network. A customized display (Figure 3), utilizing TCP/IP communications and Active-X controls, provides a moving map, airborne video, an attitude indicator, time history of a selected sensor, and numeric display of other various sensors. This display also allows for zoom, remote capture, and FTP download of images from a high-resolution digital still camera.

The instrumented pod weighs 24 pounds and requires 4 Amps at 28 Volts (112 Watts).

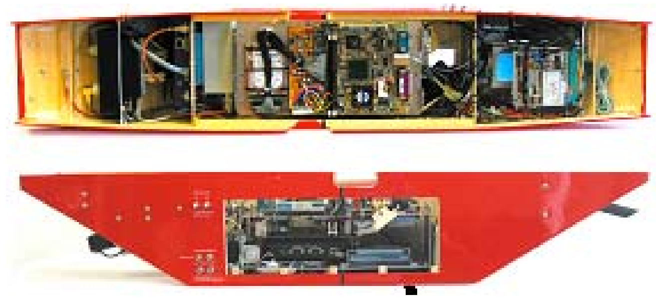

**Figure 1.** Network Smart Sensor Instrumented Pod

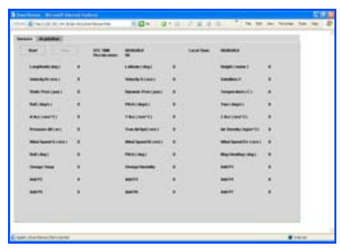

**Figure 2.** Web Display

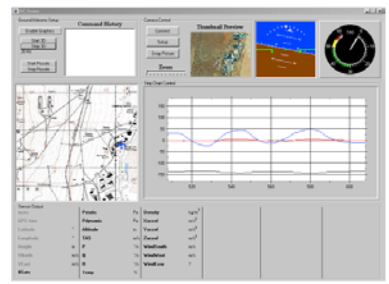

**Figure 3.** Customized Display

| Static Test of WLAN Performance* | |
|---|---|
| **Distance** | **Transfer Rate (Mbps)** |
| 100 feet | 6.5 |
| 0.5 miles | 5.5 |
| 11.3 miles | 2.5 |

*Effective Isotropic Radiated Power = 34dB

| Major System Components | |
|---|---|
| Micro ATX SBC | Avionics |
| Network Switch | Serial-to-Ethernet |
| Network Camera 30 fps | WLAN Radio link |
| Digital Camera 4Kx4K | GPS radio link |
| GPS Receiver | RF Filter/Amplifier |
| Attitude Sensor | Blade Antennas |
| Triaxial Accelerometer | Antenna Rotor System |

**Status**

The instrumented pod and tracker are fully functional. A mid 2003 flight test is planned.

**Acknowledgements**

*Mei Wei* developed the network sensors software.
*Donald Billings* instrumented the Pod.
*Tony Frackowiak* designed and built the Pod.
*Joe Leung* integrated the WLAN.
*Russ Franz* developed customized display

**Contact**

*Russ Franz*, RI (661) 276-2022

# Hot-Film Anemometry with Multiplexing

Summary
The design of a temperature-compensated hot-film anemometer with multiplexing has been completed and is now awaiting laboratory and environmental testing prior to use in flight.

Objective
The objective of this work is to reduce the weight and volume of instrumentation required to meet the requirements that flight research programs have for hot-film sensor measurements, especially for programs involving weight-limited high-altitude vehicles (ref. 1).

Approach
The approach is to extend the Dryden-designed temperature-compensated hot-film anemometer (ref. 2) to include multiplexing.

Design
The Dryden design uses a measure of the local stagnation temperature near the hot film to adjust hot-film sensor overheat and maintain a nearly constant sensitivity across the full range of flight conditions that a vehicle experiences. In the present extension of that design, low-capacitance MOSFET transistors are used as multiplexing elements for both the hot-film sensors and the stagnation temperature sensing elements.

Results & Expectations
For over a decade, Dryden has used the temperature-compensated hot-film anemometer for most of its in-flight measurement requirements. Temperature compensation is achieved by measuring the local stagnation temperature near the hot film with a resistance temperature device (RTD). The RTD is hooked up as part of the Wheatstone bridge that sets the operating point of the hot film.

For fully general-purpose use, both the hot films and RTDs need to be multiplexed. MOSFETs were selected as the multiplexing elements because of their small size. The present four-channel prototype is intended to demonstrate the feasibility of using MOSFETs without significantly compromising frequency response. Subsequent versions could conceivably support more channels.

The four-channel prototype is also designed to be attached to a commercially available data logger containing an analog-to- digital converter. With the data logger, multiple anemometers could be triggered to provide high-speed simultaneous sampling at rates up to 100,000 samples per second.

Figure 1. Photograph of four-channel prototype hot-film anemometer with multiplexing

The integration of multiplexing circuitry, anemometry, and digitization into the same package not only makes a compact design but is also expected to provide a lower system noise level than that obtainable from implementing those elements separately and distributing them in the aircraft.

Status
Initial laboratory testing is proceeding well so far. Upon completion of the laboratory testing, environmental testing will also be performed in preparation for use in flight.

References
(1) Greer et al., *Design and Predictions for a High-Altitude (Low-Reynolds-Number) Aerodynamic Flight Experiment*, NASA-TM-1999-206579, July 1999.

(2) Chiles, *The Design and Use of a Temperature-Compensated Hot-Film Anemometer System for Boundary-Layer Flow Transition Detection on Supersonic Aircraft*, NASA TM 100421, May 1988.

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# Space-Based Telemetry and Range Safety (STARS) Study


Summary

Current space launch vehicles utilize remote ground stations for telemetry data relay and range-safety. These remote sites are costly to operate and maintain. NASA's Space-Based Telemetry and Range-Safety (STARS) Study is investigating the use of space-based data relay and range-safety for Next Generation Launch Technology (NGLT) vehicles, figure 1.


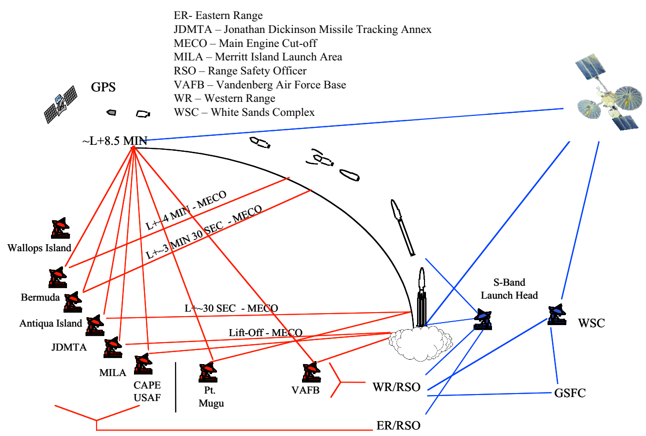


Figure 1: Current versus NGLT Data Relay

Several NASA centers including KSC, GSFC and DFRC are involved in the development and flight test of hardware to support NGLT Reusable Launch Vehicle (RLV) requirements. DFRC is responsible for the development of the range-user (RU), telemetry, data relay system and flight testing of both the range-user and range-safety (RS) systems.

STARS flight-testing will include two series of demonstration flights on a DFRC F-15B aircraft. The Phase-1 flight tests in 2003 will include demonstration of a prototype range-safety system and a range-user system, which is representative of current Expendable Launch Vehicle (ELV) satellite data links, to collect baseline performance data for current systems.

Phase-2 will include performance enhancements for the range-safety system and the development of new range-user system hardware to support increased data rates for satellite data relay. Phase-2 test flights will be conducted at DFRC in 2004.

Objective:

The primary objective of STARS is to demonstrate the capability of space-based data systems to provide RS and RU functions. This should result in a significant cost savings due to reductions in ground-based assets required to support NGLT RLV's.

The STARS project will also develop new satellite communications component technologies. This will enable the implementation of space-based RS as well as RU systems that will support data rates that are significantly higher than current ELV systems.

Status/Plans:

The STARS Phase-1 hardware has completed compatibility testing with the Tracking and Data Relay Satellite System (TDRSS) and has been installed on the F-15B aircraft.

The Phase-1 flights utilize a RS satellite transceiver with a 400bps forward link for simulated space-based flight termination commands. The RS system also includes a 10kbps satellite return link to provide system health, status and position information. Phase-1 incorporates a launch-head, similar to that implemented at current launch sites, to supplement the satellite based data relay system during the initial launch phase. The Phase-1 RU system operates at 125, 250 and 500kbps in order to characterize the performance of current RU data systems. The RU system is return link only and doesn't utilize the launch-head.

The data flow for Phase-1 is illustrated in figure 2. Satellite data relay is via Tracking and Data Relay Satellite, (TDRS), White Sands Complex (WSC), NASA Integrated Services Network (NISN) to the DFRC Mission Control Center (MCC). The DFRC Aeronautical Test Facility (ATF) has been modified to support RS uplink/downlink operation as a launch-head.

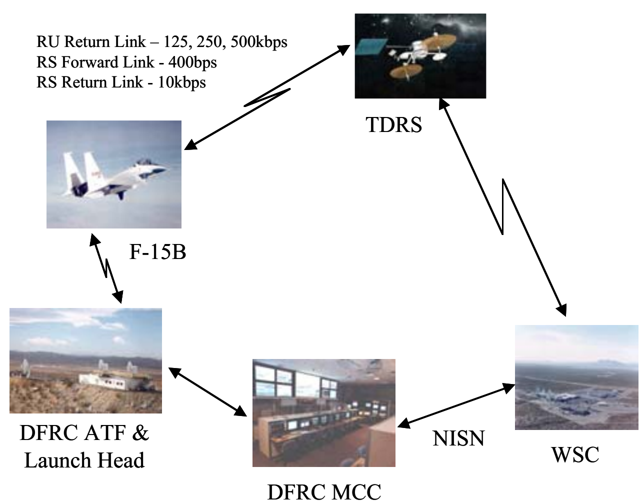


Figure 2: STARS RU and RS Data Relay

Development of new hardware for the Phase-2 STARS study has already been initiated. The Phase-1 RS system is being integrated into a single unit with enhanced performance. The RU system will utilize newly developed components to support higher data rates and IP data formats. The system includes a phased array antenna, antenna controller and transmitter. The Phase-2 RU system should support telemetry data relay at rates that are an order of magnitude greater than current ELV systems.

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# Reentry Heat Transfer and Thermal Buckling Analyses of Generic Space Plane Body Flaps


## Summary

After deorbiting, a space plane reenters the atmosphere at approximately Mach 25, and is subjected to severe aerodynamic heating during reentry flight.
The windward surface temperatures of a body flap of a generic space plane could reach as high as 3000°F.
The induced non-uniform temperature distribution over the body flap could induce thermal buckling during flight.
The purpose of the analysis is to find out if the body flap of a generic space plane is free from thermal buckling.
The results of the analysis show that the body flap will not buckle, but its buckling strength reached a minimum at 300 second rom reentry.


## Objective

To find out if the body flap of a generic space plane will buckle or not during the entire reentry flight under non-uniform heating.
Thermal buckling eigenvalues will be calculated, and to find out if the eigenvalue is
a. Greater than unity (no buckling), or
b. Less than unity (buckling takes place).

## Approach

First, the reentry aerodynamic heating was calculated based on the simulated reentry flight trajectory of a generic space plane. Next, a finite-element thermal model of the body flap was generated for reentry heat transfer analysis to calculate structural temperature distributions. Then, the nodal temperatures from the output of the thermal model were input to a finite-element structural model for the calculations of buckling eigenvalues.

## Results

1. The body flap temperature of a generic space plane reached nearly 2400°F at 800 sec. from reentry.
2. The buckling eigenvalue λ eached a minimum value λ = 1.0258 at 300 sec. from reentry.
3. The minimum eigenvalue is slightly greater than unity. Therefore, the body flap of a generic space plane will not buckle during the entire course of reentry flight.

## Contact


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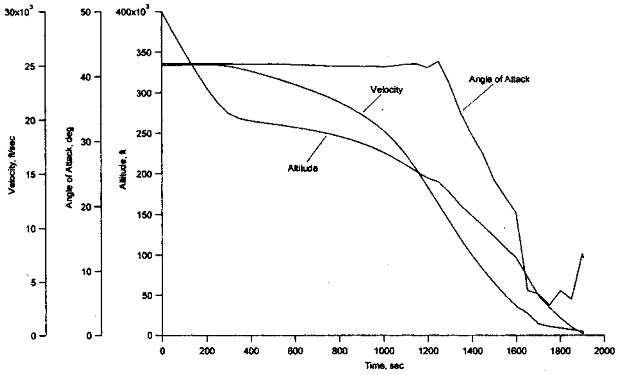

Figure 1. Reentry trajectory of a generic space plane.

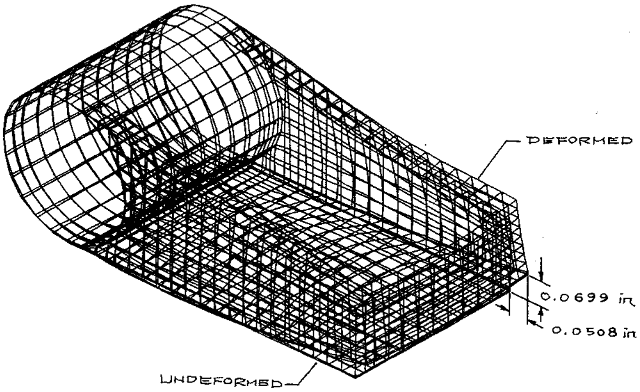

Figure 2. Deformed shape of a body flap of generic space plane.

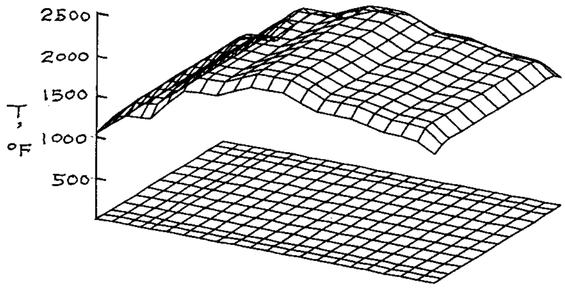

Figure 3. Temperature profile over windward surface of body flap at 300 sec.

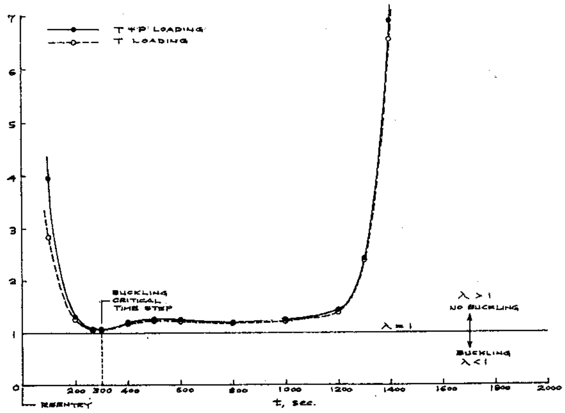

Figure 4. Plots of eigenvalues as functions of time.

# Structural Analysis of Helios Hydrogen Tanks


## Summary

Structural behavior of Helios filament-wound hydrogen tanks with geodesic and hemispheric domes were investigated. The tanks were subjected to both combined internal pressure and temperature loading as well as separate pressure and temperature loading. The stress contributions of each component loading were examined. The tank-wall/polar-boss interfacial meridian tensile stress in the hemispherical dome is found to be about 27% lower than that in the geodesic dome. Effects of material anisotropy, and of the aluminum liner on the intensities of tensile meridian stress at the tank-wall/polar-boss bonding interface, were examined.


## Objective

To perform finite-element structural analysis of the pressure vessels fabricated with geodesic dome and hemispherical dome. The structural performances of the two types of pressure vessels will be compared. Also, to investigate the criticality of interfacial bonding strength at the polar boss boundaries.

Aluminum lining of 0.014 in. thick will be introduced to examine the effect of loading sharing in the tanks.

## Approach

The filament-wound wall material of Helios $H_2$ tanks will be considered as orthotropic continuous material. The tanks will be subjected to internal pressure loading of $p = 400$ lb/in$^2$ and temperature loading of $T = -120°$ F. The structural behavior under the "p only," "T only" component loading, and the "p + T" combined loading will be investigated separately.

## Results

1. The geodesic dome tank has "near-zero" hoop stress (or hoop strain) at the cylinder/geodesic dome juncture.
2. The hemispherical dome tank has 27% lower interfacial tensile meridian stress at the polar boss boundary than the geodesic dome tank.
3. The meridian and hoop load shares by the 0.014 inch thick aluminum lining are nearly 10% and 11% respectively for both geodesic and hemispherical dome tanks.
4. Doubling the hoop stiffness greatly reduced the radial displacement jump at the cylinder/geodesic dome juncture, and totally eliminated the radial displacement jump at the cylinder/hemispherical dome juncture.

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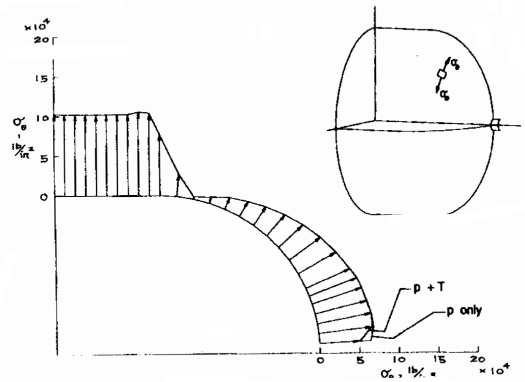



Figure 1. Meridian distributions of hoop stress $\sigma_\theta$ in geodesic dome tank; $p = 400$ lb/in$^2$; $T = -120$°F; quasi-isotropic wall.

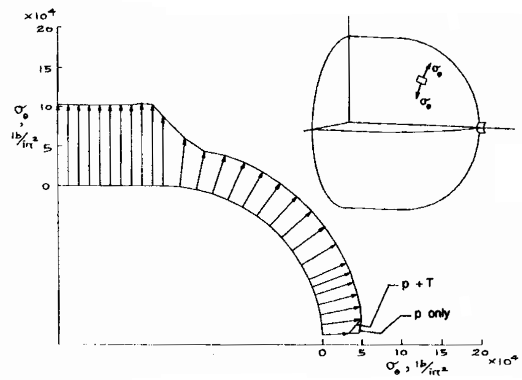



Figure 2. Meridian distributions of hoop stress $\sigma_\theta$ in hemispherical dome tank; $p = 400$ lb/in$^2$; $T = -120$°F; quasi-isotropic wall.

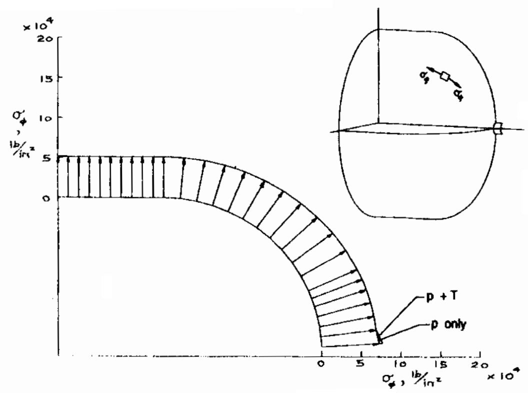



Figure 3. Meridian distributions of meridional stress $\sigma_\varphi$ in geodesic dome tank; $p = 400$ lb/in$^2$; $T = -120$°F; quasi-isotropic wall.

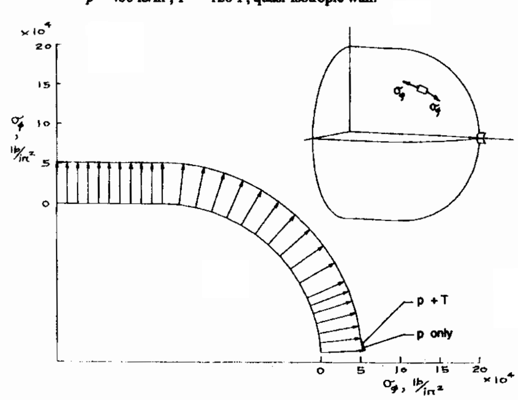



Figure 4. Meridian distributions of meridional stress $\sigma_\varphi$ in hemispherical dome tank; $p = 400$ lb/in$^2$; $T = -120$°F; quasi-isotropic wall.

# Fiber Optic Distributed Strain Sensor Experiment


<u>Summary</u>

Fiber Optic Sensor/System technology development has been underway at NASA Dryden for several years. In FY02, a fiber optic Distributed Strain Sensor (DSS) experiment has been integrated and tested in the Flight Loads Laboratory with promising results. Flight hardware has been purchased, software is being developed and is being integrated into a flight experiment that will be flown on a structures flight test fixture.


<u>Objectives</u>

To develop fiber optic based SHM *systems* for a variety of aerospace vehicle applications. Key developments and evaluations include:

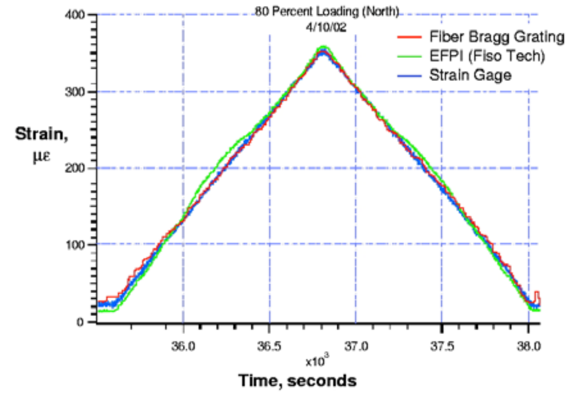
1. Flight-harden fiber-optic networks and tunable laser sources for high altitude flight applications
2. Conduct laboratory and flight test evaluation of fiber optic sensor/system technology
3. Evaluate fiber-optic strain and temperature sensors under controlled laboratory conditions prior to flight
4. Obtain in-flight fiber-optic strain and temperature measurements for both surface-mounted and embedded applications

<u>Results</u>

The laboratory DSS unit has been developed. This unit consists of the flight tunable laser, Prototype flight Optical to Electrical and signal conditioning modules, a desktop PC, and a high speed data acquisition card. The laboratory software has been developed in labview. A three sample per second data rate has been achieved. The sample rate is based on the stable tuning rate of the laser. It is believed that a nine sample per second data rate can be achieved while maintaining stable tuning of the laser.

The laboratory system demonstrated the discrimination of approximately 350 Bragg Gratings associated with DSS sensors. Sixteen sensors, co-located with conventional strain sensors, were recorded, and analyzed. The bragg gratings tracked within 2-5% of the co-located strain gages, achieved +/-15ue of noise.

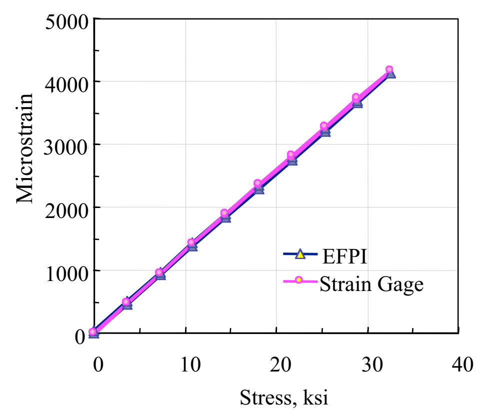
Laboratory DSS System




Laboratory Test Results of Surface-mounted Fiber Optic Sensors

The flight hardware has been purchased. The flight system consists of a flight worthy tunable laser, a fiber optic network box, and a VME chassis that contains two VME single board computers, six giga-bytes of flash based mass storage, a quad DSP board, data acquisition board, Mil-Std-1553B interface, IEEE 1394 interface, and an IEEE 488 interface. A signal conditioning board is being developed in house.

Software is being developed in-house to provide laser control, signal processing, data conversion, data storage, and data transmission to support the flight experiment. Experiment integration, flight worthiness testing, aircraft integration and flight test is targeted for late 2003.




Comparison of embedded fiber optic sensor and strain gage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# Fiber Optic Sensor Attachment Development and Performance Evaluations


**Summary**

Aerostructures Branch personnel at NASA Dryden have been evaluating and characterizing fiber optic (FO) based strain and temperature measurements for over six years. Research conducted in the Flight Loads Laboratory (FLL) has subjected FO sensors to hostile environments for in-flight applications and hot-structures ground testing (hypersonic). Sensor attachment of both fiber Bragg Gratings (FBG) and Extrinsic Fabry Perot Interferometers (EFPI) have been accomplished on metallic and composite substrates. These FO sensors, depending on the application, are currently being evaluated:

- at room and elevated temperatures
- with combined applied thermal / mechanical loads
- on large-scale structures for ground testing


**Objectives**

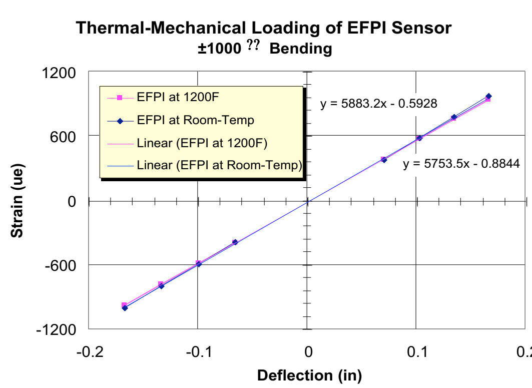
Develop attachment techniques and evaluate FO strain / temperature sensor performance for Structural Health Monitoring aerospace applications. Sensor evaluation tasks include:

1. Verify FO sensor attachment methods to graphite epoxy substrates.
2. Develop attachment techniques of EFPI sensors on both metallic and Ceramic Matrix Composites (CMC) for high temperature applications.
3. Evaluate EFPI sensor performance from room-temp to 1650 °F, under thermal and combined thermal / mechanical loads.

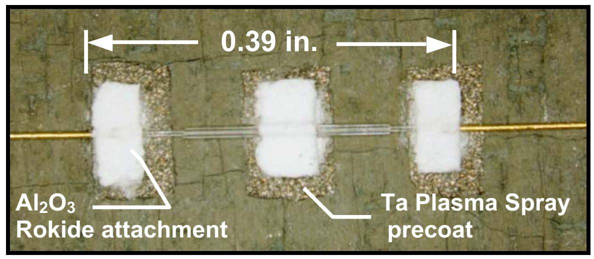
**Results**

An eight-foot long FBG run (1-cm grating spacing) was attached to a two-foot square graphite-epoxy composite panel and was loaded in the FLL Shear Load Fixture. Excellent indicated-strain correlation of the FBG's with respect to collocated conventional strain gages was achieved. Also, calibrated EFPI sensors for future embedment in the next graphite composite panel to be tested in the FLL.

Using thermal-spray processes, EFPI sensors were successfully attached to Inconel load bars. Thermal / mechanical loading of the specimens were then performed in the Strain Gage Evaluation Fixture (±1000με). Sensors performed well to 1200 °F. Data recently obtained at 1650 °F is being evaluated.

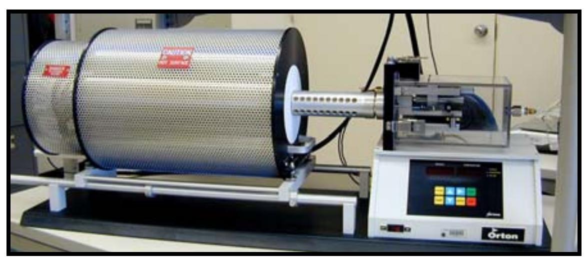



Thermal-spray procedures were also developed for the attachment of EFPI sensors to carbon-carbon substrates. High-temp installations were completed, including 14 EFPI's, on a carbon-carbon elevon control structure instrumented for ground testing in the FLL (2nd Gen RLV). Testing was completed to 100% Design Limit Load and 2000 °F in an inert Ni atmosphere chamber. The EFPI sensors were evaluated to 1650 °F.




EFPI installation on carbon/carbon substrate

Dilatometer tests were performed on both metallic and CMC substrates instrumented with EFPI strain sensors to evaluate / characterize sensor performance. These tests verified that substrate expansion (CTE) correlated well with interferometer strain output.



Laboratory dilatometer testing

The investigation into EFPI sensors on CMC materials will continue. Under NGLT and the X-37 programs, current focus is to attach and characterize these sensors on Carbon-Silicon Carbide substrates. In addition, work is underway to develop Sapphire based sensor technologies for operation in even higher temperature environments (> 2500 °F).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# Online Vehicle Health Management Toolkit


**Summary:**
NASA Dryden Flight Research Center is developing object-oriented software tools to aid the design, analysis, implementation and use of a variety of airborne and terrestrial machinery health management systems. An open, scaleable health management software system is targeted that will enable the configuration and initiation of remote algorithms that will reduce raw sensor data into relevant health information for both novice and sophisticated system designers and users. This project extends science, engineering, and research capabilities with a dynamically configurable, scalable, and cost-effective collaborative computing environment.


**Background:**
Sixty years worth of advances in sensors, digital computers, and digital communications can be integrated and leveraged to increase aerospace system safety, reliability, and performance. These improvements must be applied to systems characterized as network-centric, interoperable, adaptive, intelligent, and complex. Operating in environments that are inherently uncertain or unpredictable, the concept of *situational awareness* to support *proactive decision-making* emerges as an enabling capability that leads to improved system safety, reliability, and performance.

The goal of on-line vehicle health management is to create and deliver timely maintenance and safety related situational awareness at a reasonable cost. Vehicle health management concepts are maturing and warrant implementation, but the lack of software toolkits for designers, integrators, and users of health management systems represent an obstacle to progress. Custom applications written for specific systems have high life cycle costs and experience limited reuse and adaptation.

**Approach:**
The goal of this project is to develop a suite of network-centric object-oriented software tools to aid the design, analysis, implementation and use of health management systems. This project builds on existing network data caching service designed for managing live measurements over local and wide area networks. The underlying technology is extended here with an intuitive and flexible graphical user interface, demonstrating state-of-the-art and extensible health monitoring algorithms in an object-oriented toolkit. Specific technical objectives include

- Complete development of an object-based toolkit for assembling data and algorithms over networks using a ring-buffered network bus backbone.
- Complete development of dynamic health reporting capabilities that enable situational awareness to be communicated with Internet tools.
- Implement metadata and semantic descriptions of data and data flow structure to enable dynamic data mining and reporting, using XML in a manner representative of next-generation Web objects and services.
- Investigate and leverage smart sensor standards such as Foundation Fieldbus and IEEE 1451 in the development of metadata for information sources
- Implement a range of standard and custom health monitoring algorithms for use in the toolkit
- Test the software on a representative application to demonstrate core features and benefits.

**Status**:
A system configuration tool has been designed to present views of resources from multiple logical and hierarchical perspectives, addressing usability in the construction of complex distributed systems. An image of this configuration tool is shown in the accompanying figure. Implementation of configuration, reporting, and algorithm tools is in progress. This Phase II project is funded through the Small Business Innovation Program (Contract No. NAS4-02039, Creare, Inc.) The products being developed here will be demonstrated in collaboration with other Center activities related to propulsion health management, integrated vehicle health management, and intelligent vehicle systems


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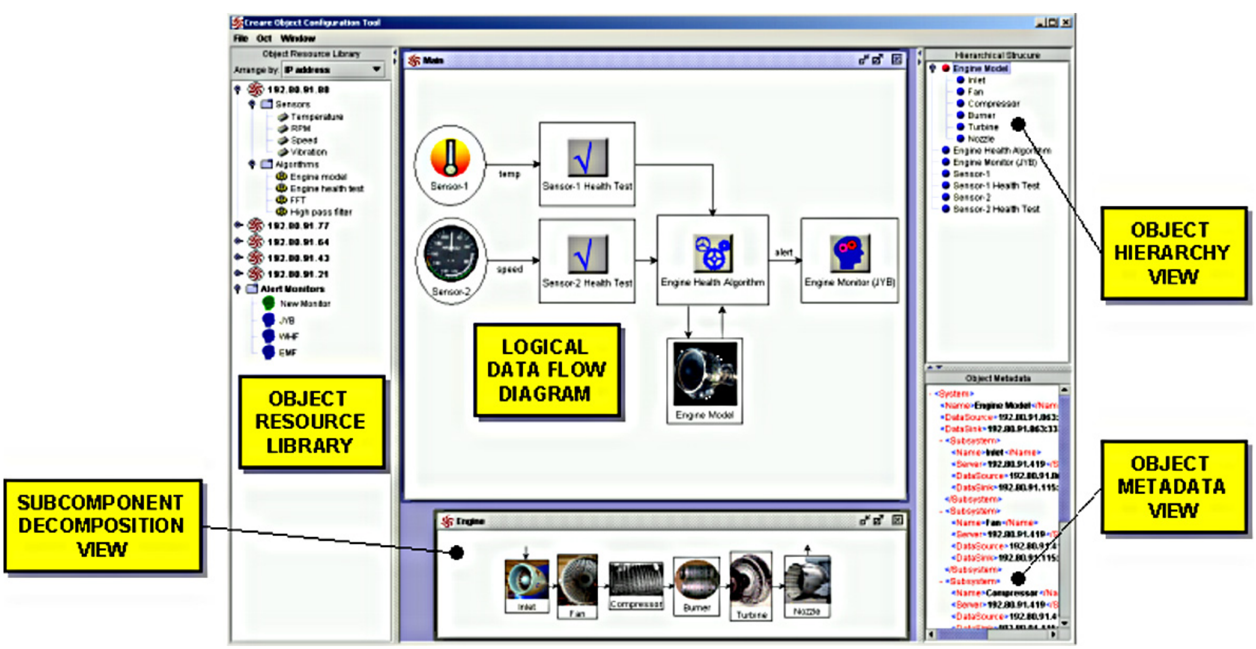


# Web-Compatible File Server for Network-Centric Testing

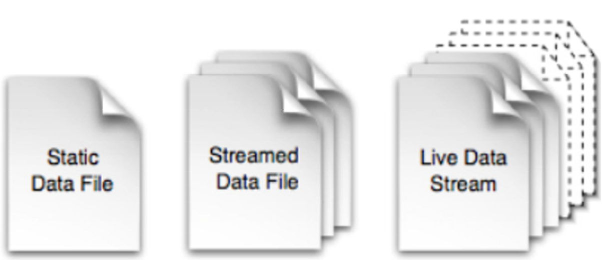

**Summary:**
NASA Dryden has developed a method to integrate live data streams with static files in a distributed network file system. This approach eliminates the need for proprietary application programmer interfaces when communicating with network-centric measurement processing, collaborative computing, or data distribution environments.


**Background:**
NASA's Goals and Objectives include enabling revolutionary capabilities by innovating new information and communication systems that increase our understanding of measured information. Technology gaps exist in the area of pooling and managing information to support situational awareness and subsequent decision-making. The gaps are significant, especially when addressing realtime data and time-constrained decision-making.

Measurement and telemetry processing applications would be improved if they could realize the full benefits of Internet style communication. Whereas the Web provides ubiquitous infrastructure for the distribution of file-based "static" data, there is no general Web solution for real-time streaming data. At best, there are proprietary products that target consumer multimedia and resort to custom point-to-point data connections.

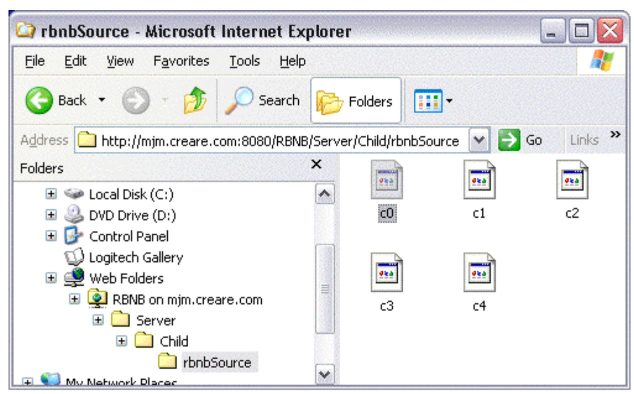
A streaming data solution has been created, built upon the existing file-based infrastructure of the Web, that tackles the many-to-many scalability, bandwidth, and latency issues common to measurement and telemetry networks applications

**Approach:**
Files are the most common way applications access data; therefore, *application independent* data access is best provided by a file paradigm. To support streams of data (i.e. files that are continuously changing), a *temporal* notion is added to files, through which time slices (data frames) are streamed to or from a network file system. As illustrated in the following figure, a unified view of static and dynamic information emerges – a static file becomes a specific time slice of a potentially larger data stream.




The solution builds on the Dryden-developed "Ring Buffered Network Bus" (RBNB) technology to cache streaming data over a hierarchical peer-to-peer network of computer servers. Implementation as a network file system is achieved via "WebDAV" (Web-Based Distributed Authoring and Versioning), an extension of HTTP protocol based on XML (Extensible Markup Language).

Launched as a Web "servlet", information in a network of servers is accessible with familiar URL syntax via browsers and other web-compatible applications. The WebDAV extensions permit write access in addition to traditional read-only web server access. Finally, the WebDAV server can be mapped as a network drive on major operating systems, thereby enabling an individual to read, write, or peruse live or static content to/from the cache server network without any special client-side interfaces. *The absence of ad hoc client side interfaces to live data is a significant achievement.* An example showing five live signals viewed as *dynamic data files* in a web folder is shown in the following figure.




**Status**:
The relatively young WebDAV standard and the stateless nature of HTTP currently result in minor cross-platform inconsistencies and some performance hits relative to interfaces based on application programmer interfaces. The prototype capabilities discussed here are contained in the V2 RBNB server, available at no charge from http://rbnb.creare.com. The V2 server contains a range of features well-suited to high performance network-centric measurement processing and has been developed with funding from NASA, DOE, DOD, and NSF.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# Research Environment for Vehicle-Embedded Analysis


**Summary:**
The Research Environment for Vehicle-Embedded Analysis on Linux (REVEAL) is an open-standards framework that facilitates the creation and deployment of real-time embedded and network distributed data systems. REVEAL is an ongoing project at NASA Dryden to evaluate the feasibility and benefits of using Linux in a modern and generic web-enabled data system for measurement and telemetry network research, by actually building such a system.


**Background:**
The overlap between aerospace technology and information technology increases monotonically. The future of aerospace vehicles, the test and evaluation industry that develops them, the manner in which communication is managed, and the airspaces in which they operate are increasingly described as network-centric, distributed, complex systems of systems that are interoperable or interact in collaborative and adaptive fashion in order to optimize performance, safety, and reliability in pursuit of various goals.

At the intersection of these aerospace industry sectors is a common need to consider acquisition, timely processing, and management of measured information as it flows to and from "the network" in these network-centric visions. At a high level, standard network services to support the timely pooling, caching, and distribution of constantly changing data would be a force multiplier by providing common solutions to related problems. At a lower level, mainstream data acquisition is a deterministic realtime activity that is not inherently compatible with best-effort, dynamic, and unpredictable network environments. Solutions for mitigating or managing latency and determinism are a chief concern in network-based measurement, and unifying approaches to solving problems in this area are needed.

It was decided that a research tool was needed to make it easier to develop and explore realtime network-distributed sensors and sensor processing systems. Dryden's interests are focused on services for on-aircraft data acquisition networks and components of future intelligent vehicle systems. In addition, the gateway between onboard systems and future wireless telemetry networks is also a prime motivator of our work. The REVEAL project was identified as a systems-oriented, cost-effective, and leading edge approach for researching network-centric acquisition and measurement applications. The Linux operating system was specifically targeted in order to gauge its capabilities and potential value in this type of application.

Baseline REVEAL hardware configuration (S/N 001)

**Approach**
REVEAL is a framework for implementing network-centric sensor acquisition and measurement processing applications. A core executive is written in C as processes running on a Linux operating system. Its small size and configurability allow it to run on devices ranging from wristwatches and cell phones to desktops and enterprise servers. The open source, extensible nature of the implementation combined with the technology forecast for Linux indicates this approach has long-term viability for an ever-increasing range of applications.

Novel features implemented in REVEAL include:

- Self-configuring, self-verifying software via simple XML documents
- Self-documenting via XML output documents
- Self-generated metadata via XML output documents
- Dynamically configurable at run-time in addition to baseline startup processing
- Ability to acquire and process local and remote data
- Use of network-centric caching middleware for interoperability with external sources and remote (e.g. desktop) access.
- Open architecture and simple API make hardware and software additions much easier
- Attention to security and integrity: processes/users can't bother or snoop on each other, by error or by purpose

For laboratory research and field tests, PC-104 based systems are being built containing an integrated sensor package with wired spares for external sensors. Measurands for bootstrapping condition monitoring and health management applications include geographical position, orientation, temperature, humidity, internal voltages, and vibration.

**Status/Plans**:
Three hardware systems are configured and running and three are in the build-up phase. Basic acquisition tasks are functional, and integration of network caching capability is in progress.

Customer interest and funding support for REVEAL development comes from Air Force and Navy sources. Local planning and advocacy have begun to apply REVEAL to Integrated Vehicle Health Management and Intelligent Vehicle Systems problems. These plans envision REVEAL as part of the solution for on-board system-wide information integration and management. The plan is to run REVEAL in a flight environment on VME-based hardware and (with a five-phase approach) progressively work toward implementing network and application layer integration services that support situational awareness in intelligent applications like proactive maintenance scheduling, mission management, and vehicle control.


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# Summary of the Meteorological Support for the Pathfinder Plus UAV Coffee Mission

**Summary**

In the summer of 2002, the Pathfinder Plus (PF+) Solar Powered UAV was deployed to the Pacific Missile Range Facility (PMRF), Kauai, HI, to demonstrate that a solar powered UAV can be used as airborne platform for imaging the large Coffee fields on Kauai. The payload consisted of two digital cameras (one visible and one near-infrared) individually sealed inside two pressurized pods mounted under the center wing panel of PF+. The images were taken at an altitude of 21000 feet MSL. The high-resolution images can be used to locate areas in the coffee plantation where the coffee beans are ripe and ready to harvest. The images were processed real-time and presented to the harvest manager in order to plan the picking of the ripe, ready for harvest, beans. The idea is to reduce the picking of unripe beans. To accomplish the mission safely and successfully, accurate and timely meteorological prediction and in-flight monitoring were crucial. To support this task, a meteorologist from Code RA was deployed to PMRF to support the mission as a member of the flight crew. Similar support was provided to the PF+ Telecommunication Demonstration flight tests performed during the summer (three telecommunication missions were accomplished).

Up to three flights were planned for the Coffee mission during the deployment, however, only one was accomplished due to degrading weather conditions. The single flight was extremely successful with ~90% of the customer's objectives met. The missions were made possible by a team that consisted, in part, of NASA-Dryden, NASA-Ames, Clark University, AeroVironment, and the Kauai Coffee Company.

Objective: To provide flight team current and forecast weather conditions that will improve the likelihood of a safe and successful flight-test operation.

Justification: Meteorological support is critical due to the basic design and limitations of PF+. It is possible the aircraft may be lost due to wind, cloud and turbulence information not being constantly updated to the pilots and mission planners before and during the flight. In addition, it was required that the area over the coffee fields, or targets, needed to be clear of clouds in order to get usable images. However, the coffee fields are in an area where low clouds (2000-4000 feet AGL) are a common occurrence. To work around clouds, real-time coordination between mission planners, meteorologist, and payload team was a must to find and maneuver to cloudless areas of the coffee fields.

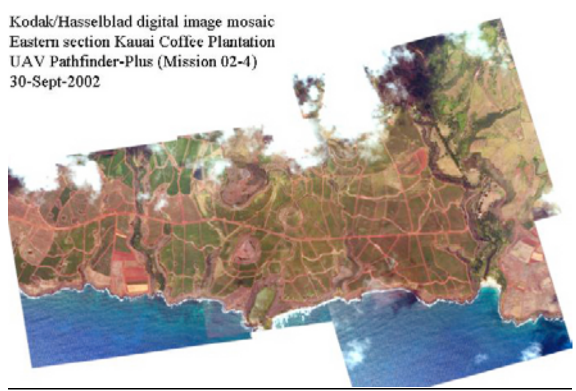
Approach: Meteorological forecasts of surface and upper level wind conditions begin 48 hours before flight day. During the crew briefing, performed 24 hours prior to flight, a more detailed weather briefing is provided. Current surface conditions, upper level data taken from weather balloon observations and clouds conditions from satellite images are reviewed along with the predicted conditions for flight day. On flight day, early morning weather brief was performed prior to aircraft hangar rollout. A final go-no go review of weather elements is performed about 2 hours before takeoff. After takeoff, periodic updates based on weather balloons and satellite data is provided to the pilot and mission planners. While the PF+ is on station, updates on current cloud conditions and trends are given to the Payload Coordinator in order to optimize imaging of clear target areas. At approximately 2 hours prior to landing, a final weather forecast is issued to the pilot to estimate earliest possible landing time and to designate runway for approach. After landing, surface conditions are monitored until aircraft is safely stored in the hangar.

Status: One successful Coffee flight was accomplished.
PF02-4 September 30,2002:

- Takeoff occurred at 0858 HST under mostly clear skies.
- Clouds obscured most of Coffee fields as PF+ came on station (1144 HST) at a loiter altitude of 21000 feet MSL.
- Due of the ability of PF+ to loiter and fly to clear areas for nearly 3 hours, imaging of ~90% of the primary target area was achieved.
- PF+ successfully landed in a 6 knot wind at 2018 HST
- The final flight attempts between October 3rd-7th were scrubbed due to adverse weather conditions (high surface winds and/or overcast skies)
- Flight PF02-4 concluded PF+ deployment for the year

Pathfinder Plus In Flight With Kodak/Hasselblad Payload


View from PF+ Of Cloud Cover Over Coffee Fields When Arriving On Station




Composite Payload Image of the Coffee Fields

Contacts: Casey Donohue, AS&M, x-2768

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1. Allen, Michael J., Jack Ryan, James F. Parle, and Curtis E. Hanson, *String Stability of a Linear Formation Flight Control System*, NASA/TM-2002-210733, August 2002.

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## Tech Briefs and Patents

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Frank Burcham, John Burken, Jeanette Le
Emergency Landing Using Thrust Control and Shift of Weight
Published May 2002

Martin Brenner, Peter Thompson, David Klyde
Wavelet-Based Time-Varying Models of Pilots in Control Loops
Published September 2002

Timothy Moes, Gregory Noffz
Control Derivatives of the F-18 Airplane
Published September 2002

Richard Tracy, Daniel Banks, James Chase, Rodney Schapel
Flight Research on Supersonic Laminar Flow
Published June 2002

Angela Beaver, Donald Greer
Study of Turbulent Boundary Layer of the F-15B Airplane
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Tony Trent
Fiber-Optic Rotary Joint for Passing High-Definition Video
Published April 2002

Edward Haering, David Richwine
Hardware and Software for Air-to-Air Schlieren Imaging
Published January 2002

Edward Teets, Natalie Salazar
Wind and Mountain Wave Observation From a Flight Test of a Solar-Powered Airplane
Published September 2002

Anthony Piazza
Temperatures-Compensation Method for High-Temperature Strain Gauges
Published August 2002

Thomas Horn, Vijay Dhir, Shanjuan Jiang
Characterization of Heat-Flux-Gauge Calibration System
Published May 2002

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An Alumina Encapsulated Strain Gauge, Not Mechanically Attached To The Substrate, Used To Temperature Compensate An Active High Temperature Gauge In Half-Bridge Configurations
DRC-096-074

Algorithm And Test Technique For A Frequency Excitation Using An Optimized Multiple Frequency Sweep Waveform (Sweepstack)
DRC-099-006

Wind Advisory System
DRC-099-016

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